

NPS-57Va73061A

NAVAL POSTGRADUATE SCHOOL

Monterey, California



CALCULATING PROCEDURE OF SEA-LEVEL STATIC
PERFORMANCE OF TWO-SPOOL AFTERBURNING
BYPASS JET ENGINE

by

M. H. Vavra

June 1973

Approved for public release, distribution unlimited

NAVAL POSTGRADUATE SCHOOL
Monterey, California 93940

Rear Admiral M. B. Freeman
Superintendent

M. U. Clauser
Provost

ABSTRACT:

A calculating procedure is presented for the sea-level static performance of duct burning and afterburning bypass jet engines that have a low pressure and a high pressure spool. Performance values can be determined also for operation without reheat. Influence of temperature and fuel/air ratio on the thermodynamic properties of air and combustion gases is taken into account. A calculating program for a Monroe 1880-43 programmable electronic desk calculator is described which makes it possible to evaluate effects of changes of parameters on performance with minimum effort.

The program will be used to establish the characteristics of compressors required for propulsive units of later generation Navy air-superiority fighter aircraft, to investigate whether the Turbo-Propulsion Laboratory of NPS would be capable of undertaking research and development work of such machines.

Programs of the type presented, and the use of modern programmable desk calculators, will also be of great value for instructional purposes. Teachers can then concentrate on the fundamental nature of particular topics and need not waste time on lengthy derivations, or on simplifications and approximations that are introduced only to solve equations with elementary means. The students would be relieved of the drudgery of routine hand calculations that do not contribute to a better understanding of the subject matter.

This study has been supported, in part, by:

Naval Air Systems Command, Code 310
AIRTASK No. A 310 310A/186A/3R02403001 Ref. b

TABLE OF CONTENTS

	Page
1. Objective	1
2. Introduction	2
3. Thermodynamics of Real Gases	3
4. Fuel/Air Ratio of Combustor	11
5. Mixing of Flows at Constant Pressure	13
6. Low and High Compressor Calculations	15
7. High Turbine Calculation	16
8. Expansion Process	17
9. Low Turbine Calculations	18
10. Jet Nozzle Discharge Velocity	18
11. Engine Performance	19
12. Engine Thrust vs. Outer Diameter of Low Compressor	19
13. Calculating Procedure	21
14. Examples	26
Table I(1) Example A (Form 1)	29
Table I(2) Example A (Form 2)	30
Table II(1) Example B (Form 1)	31
Table II(2) Example B (Form 2)	32
Figure 1. Schematic of Bypass Jet Engine with Duct and Afterburner	33
Figure 2. Combustor	34
Figure 3. Mixing Process	34
Figure 4. Velocity Diagram at Tip of Low Compressor	34
Figure 5. Compression Process	35

Figure 6a.	$h = F(T, f)$	36
Figure 6b.	$h = F(T, f)$	37
Figure 7a.	$\varphi = F(T, f)$	38
Figure 7b.	$\varphi = F(T, f)$	39
Appendix A.	Operating Instructions of Programs VA 513 and VA 514 for Jet Engine with Ductburner and Afterburner	40
Appendix B.	Operating Instructions of Programs VA 513 and VA 514 for Jet Engine without Ductburner and Afterburner	48
Appendix C.	Listing of Programs	51
	Program VA 513	52
	Program VA 514	59
	Contents of Scratch Pad Registers	99
	Contents of Main Data Registers	100

CALCULATING PROCEDURE OF SEA-LEVEL STATIC
PERFORMANCE OF TWO-SPOOL AFTERBURNING
BYPASS JET ENGINE

by

M. H. VAVRA

1. OBJECTIVE

To determine the sea-level static (SLS) performance of a bypass jet engine with or without duct burner and afterburner, and to establish a calculating program for a Monroe Model 1880-43 programmable hand calculator that can be used for optimization and systems analyses.

2. INTRODUCTION

Figure 1 shows a schematic of the engine under consideration with the station identification numbers that will be used in the report.

Total pressures and temperatures at the different stations are denoted by P and T with subscripts corresponding to the indices of the stations. Static pressures are denoted by P_s and static temperatures by T_s .

The total cooling air for the blades ($\dot{w}_{BC}$) and the disks ($\dot{w}_{DC}$) of the high turbine is taken as a fraction ξ of the engine air ($\dot{w}_E$), or

$$\xi = \frac{\dot{w}_{BC} + \dot{w}_{DC}}{\dot{w}_E}$$

The bypass flow rate $\dot{w}_{BP}$ is

$$\dot{w}_{BP} = b \dot{w}_E$$

where b is the bypass ratio. After the high turbine, the cooling air $\xi \dot{w}_E$, which is supposed to be at the temperature T_3 , since the process in the high turbine is considered to be adiabatic, is mixed with the flow rate $(1-\xi) \dot{w}_E$ of the high turbine which is at the temperature T_5 .

The fuel/air ratio of the main burner is

$$f_B' = \frac{\dot{w}_{fB}}{(1-\xi) \dot{w}_E}$$

which is also the fuel/air ratio of the gas passing through the high turbine. After the mixing of cooling air and high turbine flow rate (station 6) the fuel/air ratio is

$$f_B = \frac{\dot{w}_{fB}}{\dot{w}_E} = (1-\xi) f_B'$$

which is the fuel/air ratio of the gas flow through the low turbine. The duct burner is taken as part of the afterburner and it is supposed that the bypass flow and the flow leaving the low turbine are heated to the same temperature $T_9 = T_{10}$. The fuel/air ratio necessary to heat $\dot{w}_{BF}$ to T_9 is

$$f_{DB} = \frac{\dot{w}_{fDB}}{\dot{w}_{BP}} = \frac{w_{fDB}}{b \dot{w}_E}$$

The fuel flow rate $\dot{w}_{fAB}$ of the afterburner is expressed by

$$f_{AB} = \frac{\dot{w}_{fAB}}{\dot{w}_E}$$

The total fuel/air ratio f_N referred to the total air flow rate

$$\dot{w} = \dot{w}_E + \dot{w}_{BP} = (1+b) \dot{w}_E$$

is

$$f_N = \frac{f_B + f_{AB} + b f_{DB}}{1 + b} \quad (1)$$

This fuel/air ratio exists at station 11 ahead of the nozzle, and the total nozzle flow rate is

$$\dot{w}_N = (1+f_N) \dot{w}$$

The enthalpy of the flow rate $\dot{w}_N$ at station 11 is supposed to be that at the temperature $T_{11} = T_9 = T_{10}$ for the fuel/air ratio f_N . Hence it is assumed that the gas flows through the duct and afterburner are completely mixed at station 11.

The drop in total pressure ΔP through a flow passage is expressed by the pressure drop coefficient

$$\lambda = \frac{\Delta P}{P_{\text{inlet}}}$$

where P_{inlet} is the total pressure ahead of the flow passage.

For the inlet nozzle,

$$\lambda_I = \frac{P_0 - P_1}{P_0}$$

For the bypass duct,

$$\lambda_{BP} = \frac{P_2 - P_7}{P_2}$$

For the main burner,

$$\lambda_B = \frac{P_3 - P_4}{P_3}$$

It is assumed that the pressures P_7 and P_8 , ahead of duct and afterburner, are equal and that the respective pressure drop coefficients λ_{DB} and λ_{AB} are equal also, or

$$\lambda_{DB} = \lambda_{AB} = \frac{P_7 - P_{11}}{P_7} = \frac{P_8 - P_{11}}{P_8}$$

The pressure P_7 is then

$$P_7 = (1 - \lambda_I) (1 - \lambda_{BP}) \frac{P_2}{P_1} P_0$$

The pressure P_8 equals

$$P_8 = (1 - \lambda_I) (1 - \lambda_B) \frac{P_3}{P_1} \frac{P_5}{P_4} \frac{P_8}{P_5} P_0$$

The total compression ratio P_3/P_1 will be chosen, and the pressure P_5/P_4 of the high turbine is obtained from the condition that the high turbine with the inlet temperature T_4 must be capable of driving the high compressor. Hence with $P_8 = P_7$ and $P_6 = P_5$, the pressure ratio P_8/P_5 or P_8/P_6 of the low turbine is

$$\frac{P_8}{P_5} = \frac{P_8}{P_6} = \frac{1 - \lambda_{BP}}{1 - \lambda_B} \frac{P_2/P_1}{(P_3/P_1) (P_5/P_4)} \quad (2)$$

The pressure ratio P_{12}/P_{11} of the jet nozzle then becomes with $P_{12} = P_0$

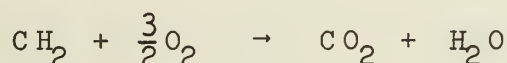
$$\frac{P_{12}}{P_{11}} = \frac{P_0}{P_{11}} = \frac{P_0}{P_7 (1 - \lambda_{AB})} = \frac{1}{(1 - \lambda_I) (1 - \lambda_{BP}) (1 - \lambda_{AB}) (P_2/P_1)} \quad (3)$$

Hence, in addition to P_3/P_1 , the pressure ratio P_2/P_1 of the low compressor is also a variable parameter that has to be chosen.

3. THERMODYNAMICS OF REAL GASES

The data of Ref. 1 are used to establish the fuel/air ratios in the burners, and to calculate the enthalpies of air and combustion gases. Reference 1 assumes that the specific heats are functions of temperature and fuel/air ratio only. Even for pressure ratio P_3/P_1 of 30 and higher the effect of pressure on specific heat is indeed negligible.

For a fuel of the composition $(CH_2)_n$, the chemical process for complete combustion is



With the molecular weights:

$$M_{H_2} = 2.016$$

$$M_{O_2} = 32$$

$$M_C = 12.010$$

there is

$$14.026 \text{ lbm } CH_2 + 48 \text{ lbm } O_2 \rightarrow 44.010 \text{ lbm } CO_2 + 18.016 \text{ lbm } H_2O$$

or, for f pounds of fuel,

$$f \text{ lbm fuel} + 3.422 f \text{ lbm } O_2 \rightarrow 3.138 f \text{ lbm } CO_2 + 1.284 f \text{ lbm } H_2O$$

Ref. 1. Vanco, M. R. "Computer Program for Design-Point Performance of Turbojet and Turbofan Engine Cycles," NASA TM X-1340, Febr. 1967.

In one pound of air there are:

$$\begin{aligned}
 0.2314 \text{ lbm } O_2 & \quad (M_{O_2} = 32.0) \\
 0.7552 \text{ lbm } N_2 & \quad (M_{N_2} = 28.016) \\
 0.0129 \text{ lbm Argon} & \quad (M_{Ar} = 39.944) \\
 0.0005 \text{ lbm } CO_2 & \quad (M_{CO_2} = 44.010)
 \end{aligned}$$

The combustion products, if f pounds of fuel are burned with one pound of air, have the following composition:

$$\begin{aligned}
 \bar{m}_{O_2} &= 0.2314 - 3.422 f \quad \text{lbm} \\
 \bar{m}_{CO_2} &= 0.0005 + 3.138 f \quad \text{lbm} \\
 \bar{m}_{H_2O} &= 1.284 f \quad \text{lbm} \\
 \bar{m}_{N_2} &= 0.7552 \quad \text{lbm} \\
 \bar{m}_{Ar} &= 0.0129 \quad \text{lbm} \\
 \hline
 \bar{m}_G &= 1 + f \quad \text{lbm}
 \end{aligned}$$

This list shows that the stoichiometric fuel/air ratio, obtained if no oxygen is present in the combustion gases (or $\bar{m}_{O_2} = 0$), equals

$$f_{\max} = \frac{0.2314}{3.422} = 0.0675 \frac{\text{lbm fuel}}{\text{lbm air}}$$

The specific heat c_{pG} of the combustion gases per lbm of mixture equals

$$c_{pG} = \frac{\sum \bar{m}_i c_{pi}}{1 + f} \quad (4)$$

where i refers to the components listed above. The molecular weight M_G of the combustion gas is obtained from

$$M_G = \frac{1 + f}{\sum \frac{\bar{m}_i}{M_i}}$$

With the mass $\bar{m}_i$ of the components of the above table and their molecular weights M_i

$$M_G = \frac{1 + f}{0.034522 + 0.035648 f} \quad (5)$$

and

$$R_G = \frac{1545.43}{M_G} \left(\frac{\text{ft} - \text{lb}}{\text{lbm}, ^\circ\text{R}} \right)$$

Then for air with $f = 0$,

$$M_G = M_A = 28.9670$$

and

$$R_G = 53.3513 \left(\frac{\text{ft} - \text{lb}}{\text{lbm}, ^\circ\text{R}} \right)$$

The constituents of the combustion gases have specific heats c_{pi} which can be expressed by

$$c_{pi} = A_i + B_i(10^{-3}) T + C_i(10^{-6}) T^2 + D_i(10^{-9}) T^3 + E_i(10^{-12}) T^4 \quad (6)$$

Reference 1 gives the coefficients A_i to E_i for the different constituents in accordance with Ref. 2. The specific heat c_{pG} of Eq. 4 can therefore be expressed by a relation of the type

$$c_{pG} = \frac{1}{1 + f} F(f, T) \quad (7)$$

where c_{pG} is in Btu/(lbm, $^\circ\text{R}$) and T in $^\circ\text{R}$.

Ref. 2. NASA SP-3001, 1963.

From the first law of thermodynamics

$$dq = T ds = du + \frac{p dv}{J} = dh - \frac{v dp}{J}$$

Further, since

$$dh = c_p dT \quad (8)$$

and

$$v = \frac{R_G T}{p}$$

there is

$$ds = c_p \frac{dT}{T} - \frac{R_G}{J} \frac{dp}{p}$$

For an isentropic process with $ds = 0$,

$$\frac{R_G}{J} \frac{dp}{p} = c_p \frac{dT}{T}$$

This equation integrated gives

$$\frac{R_G}{J} \ln p = \int_0^T \frac{c_p}{T} dT = \varphi \left(\frac{\text{Btu}}{\text{lbm, } ^\circ\text{R}} \right) \quad (9)$$

if $p = 1$ for $T = 0$.

If an isentropic process takes place from T_i, P_i to P_e, T_e' there is

$$\frac{R_G}{J} \ln \left(\frac{P_e}{P_i} \right) = \int_0^{T_e'} \frac{c_p}{T} dT - \int_0^{T_i} \frac{c_p}{T} dT = \varphi_{e'} - \varphi_i \quad (10)$$

and

$$\frac{P_e}{P_i} = e^{\left[\frac{J}{R_G} (\varphi_{e'} - \varphi_i) \right]} \quad (11)$$

where

$$\frac{J}{R_G} = \frac{J}{R_O} \frac{M_G}{M_O} = \frac{778.16}{1545.43} M_G = 0.5035233 M_G$$

It is evident that for a given pressure ratio P_e/P_i and an inlet temperature T_i the isentropic temperature T_e' must be found with an iterative process.

Equation 8 integrated gives

$$h = \int_0^T c_p dT \quad \left(\frac{\text{Btu}}{\text{lbm Gas}} \right) \quad (12)$$

if $h = 0$ for $T = 0$

Turbomachinery calculations are simplified if average values of $\bar{c}_p$ and $\bar{\gamma} = \bar{c}_p/\bar{c}_v$ are introduced, after the inlet and exit conditions have been established with accurate methods. For an isentropic process with known quantities T_i, T_e', P_i, P_e ; and h_i, h_e' there exist two ways to determine $\bar{\gamma}$. From

$$h_e' - h_i = \bar{c}_p (T_e' - T_i)$$

and

$$\bar{c}_v = \bar{c}_p - R_G/J$$

there is

$$\bar{\gamma} = \bar{\gamma}_1 = \frac{\bar{c}_p}{\bar{c}_v} = \frac{1}{1 - \frac{R_G}{J} \frac{T_e' - T_i}{h_e' - h_i}}$$

From Eq. 10, however, with

$$\frac{R_G}{J} \ln \left(\frac{P_e}{P_i} \right) = \bar{c}_p \ln \left(\frac{T_e'}{T_i} \right) = \varphi_e' - \varphi_i$$

$$\bar{\gamma} = \bar{\gamma}_2 = \frac{1}{1 - \frac{R_G}{J} \frac{\ln(T_e'/T_i)}{\varphi_{e'} - \varphi_i}}$$

Experience has shown that the value $\bar{\gamma}_2$ gives closer correspondance with real gas data than $\bar{\gamma}_1$. However, to determine the local value of $\gamma = \gamma_L$ at a given static temperature T_s and fuel/air ratio f , it is necessary to apply the same method as for $\bar{\gamma}_1$, or

$$\gamma_L = \frac{1}{1 - \frac{R_G}{J} \frac{T_s}{h_s}}$$

The velocity of sound "a" at the temperature T_s then becomes

$$a = \sqrt{\gamma_L g R_G T_s} = \sqrt{\frac{g R_G T_s}{1 - \frac{R_G}{J} \frac{T_s}{h_s}}}$$

where h_s is the enthalpy that corresponds to the static temperature T_s .

In Ref. 1 the integrals of Eqs. 9 and 12 have been calculated. A total of ten constants appears in the results, namely,

$$C_1 = 0.24062$$

$$C_2 = 0.017724 (10^{-3})$$

$$C_3 = 0.038056 (10^{-6})$$

$$C_4 = 0.012662 (10^{-9})$$

$$C_5 = 0.0013012 (10^{-12})$$

$$D_1 = 0.22091$$

$$D_2 = 0.51822 (10^{-3})$$

$$D_3 = 0.19462 (10^{-6})$$

$$D_4 = 0.045089 (10^{-9})$$

$$D_5 = 0.0043275 (10^{-12})$$

Then,

$$\begin{aligned} \phi = \frac{1}{1+f} \left[C_1 \ln T - C_2 T + \frac{C_3}{2} T^2 - \frac{C_4}{3} T^3 + \frac{C_5}{4} T^4 \right] \\ + \frac{1}{1+f} \left[D_1 \ln T + D_2 T - \frac{D_3}{2} T^2 + \frac{D_4}{3} T^3 - \frac{D_5}{4} T^4 \right] \end{aligned} \quad (13)$$

and

$$h = \frac{1}{1+f} h_A + \frac{f}{1+f} h_G \quad \left(\frac{\text{Btu}}{\text{lbm Gas}} \right) \quad (14)$$

where h_A is due to the air, and h_G due to the combustion gases of the mixture. Then

$$h_A = \left[C_1 T - \frac{C_2}{2} T^2 + \frac{C_3}{3} T^3 - \frac{C_4}{4} T^4 + \frac{C_5}{5} T^5 \right] \quad (15)$$

$$h_G = \left[D_1 T + \frac{D_2}{2} T^2 - \frac{D_3}{3} T^3 + \frac{D_4}{4} T^4 - \frac{D_5}{5} T^5 \right] \quad (16)$$

The quantities h and ϕ are shown in Figs. 6 and 7 as functions of T and f .

4. FUEL/AIR RATIO OF COMBUSTOR

Figure 2 shows a combustion chamber where $\dot{w}_i$ (lbm/s) of air with a fuel/air ratio f_i enter the combustor at the temperature T_i . To be determined is the fuel flow rate $\dot{w}_f$ necessary to heat this mixture to the temperature T_e . The fuel enters the combustor at the temperature T_f and it is supposed that the combustor efficiency is η , or that $\eta(\text{LHV})$ Btu's are released per lbm of fuel during combustion, where (LHV) is the lower heating value of the fuel in Btu/lbm.

A heat balance gives

$$\dot{w}_i (1 + f_i) h_i + \dot{w}_f h_f + \dot{w}_f \eta(\text{LHV}) = [\dot{w}_i (1 + f_i) + \dot{w}_f] h_e$$

With

$$\dot{w}_f = \Delta f \dot{w}_i$$

$$f_e = f_i + \Delta f$$

and Eq. 14,

$$h_{Ai} + f_i h_{Gi} + \Delta f h_f + \Delta f \eta(\text{LHV}) = h_{Ae} + (f_i + \Delta f) h_{Ge}$$

or

$$\Delta f [h_f + \eta(\text{LHV}) - h_{Ge}] = h_{Ae} - h_{Ai} + f_i (h_{Ge} - h_{Gi})$$

and

$$\Delta f = \frac{\dot{w}_f}{\dot{w}_i} = \frac{h_{Ae} - h_{Ai} + f_i (h_{Ge} - h_{Gi})}{h_f + \eta(\text{LHV}) - h_{Ge}}$$

All enthalpies are zero at $T = 0^\circ \text{ R}$.

For JP-4 fuel the lower heating value is 18,400 Btu/lbm, and its specific heat is about 0.5. Hence at a chosen fuel temperature of 520° R , or $h_f = 260 \text{ Btu/lbm}$, there is

$$\Delta f = \frac{h_{Ae} - h_{Ai} + f_i (h_{Ge} - h_{Gi})}{\eta(18,400) + 260 - h_{Ge}} \quad (17)$$

with h_A and h_G from Eqs. 15 and 16. With $f_e = f_i + \Delta f$ the enthalpy h_e is obtained from Eq. 14.

Equation 17 can be used for all three combustors. For the main burner there are:

$$T_i = T_3$$

$$f_i = 0$$

$$T_e = T_4$$

$$\eta = \eta_B$$

$$\Delta f = f_e = f_B'$$

For the after-burner:

$$T_i = T_8$$

$$f_i = f_B = (1 - \xi) f_B'$$

$$T_e = T_{10}$$

$$\eta = \eta_{AB}$$

$$\Delta f = f_{AB}$$

$$f_e = f_B + f_{AB}$$

For the duct burner:

$$T_i = T_2$$

$$f_i = 0$$

$$T_e = T_9 = T_{10}$$

$$\eta = \eta_{AB}$$

$$\Delta f = f_e = f_{DB}$$

The fuel/air ratios $f_B + f_{AB}$, and/or f_{DB} , have to be lower than the stoichiometric ratio $f_{\max} = 0.0675$.

5. MIXING OF FLOWS AT CONSTANT PRESSURE

The process illustrated in Fig. 3 will be used to evaluate the conditions that occur after the high turbine, where the cooling air is mixed with the turbine discharge, and those where the bypass and the engine flow mix before entering the jet nozzle. With the symbols of Fig. 4, on assuming an adiabatic process,

$$\dot{w}_i(1 + f_i) h_i + \dot{w}_{ii}(1 + f_{ii}) h_{ii} = \left[\dot{w}_i(1 + f_i) + \dot{w}_{ii}(1 + f_{ii}) \right] h_e$$

Let

$$\dot{w}_e = \dot{w}_i + \dot{w}_{ii} = (1 + \zeta) \dot{w}_i$$

or

$$\zeta = \frac{\dot{w}_{ii}}{\dot{w}_i} \quad (18)$$

Then

$$h_e = \frac{(1 + f_i) h_i + \zeta(1 + f_{ii}) h_{ii}}{1 + \zeta + f_i + \zeta f_{ii}} \quad (19)$$

and

$$f_e = \frac{f_i + \zeta f_{ii}}{1 + \zeta} \quad (20)$$

With Eq. 14, there is from Eq. 19,

$$h_e = \frac{h_{Ai} + f_i h_{Gi} + \zeta h_{Aii} + \zeta f_{ii} h_{Gii}}{(1 + \zeta) + f_i + \zeta f_{ii}}$$

For the known values of h_e and f_e the temperature T_e is obtained by iterating Eq. 14.

For the mixing ahead of the jet nozzle, there is $T_i = T_{ii}$, or $h_{Ai} = h_{Aii}$, and $h_{Gi} = h_{Gii}$. Then, with Eq. 20

$$h_e = \frac{(1 + \zeta)h_{Ai} + h_{Gi}(f_i + \zeta f_{ii})}{(1 + \zeta) + f_i + \zeta f_{ii}} = \frac{h_{Ai} + f_e h_{Gi}}{1 + f_e}$$

However

$$h_e = \frac{1}{1 + f_e} h_{Ae} + \frac{f_e}{1 + f_e} h_{Ge}$$

Hence, as could be expected, there must be

$$h_{Ae} = h_{Ai} \text{ and } h_{Ge} = h_{Gi}$$

and the temperature after the mixing process is equal to $T_i = T_{ii}$. Hence h_e can be calculated directly for $T_i = T_{ii}$ and the fuel/air ratio f_e of Eq. 20.

For the mixing process after the high turbine there are:

$$\zeta = \xi / (1 - \xi)$$

$$T_i = T_5$$

$$f_i = f_B'$$

$$T_{ii} = T_3$$

$$f_{ii} = 0$$

$$f_e = f_B$$

For the mixing process ahead of the jet nozzle:

$$\zeta = b$$

$$T_i = T_{ii} = T_9 = T_{10}$$

$$f_i = f_B + f_{AB}$$

$$f_{ii} = f_{DB}$$

$$f_e = f_N$$

6. LOW AND HIGH COMPRESSOR CALCULATIONS

Figure 5 represents a compression process in an entropy diagram. The pressure ratio P_e/P_i of both low and high compressor will be chosen. Then

$$\Delta h_{is} = h_e' - h_i$$

and the specific work necessary to drive the compressor is, with the compressor efficiency η_c ,

$$\Delta h_w = \frac{\Delta h_{is}}{\eta_c}$$

From Eq. 10

$$\varphi_e' = \varphi_i + \frac{R_G}{J} \ln \left(\frac{P_e}{P_i} \right)$$

where both values of φ are for $f = 0$. From φ_{T2} , the temperature T_e' is obtained by an iteration. Then, from Eq. 15

$$h_e' = h_A(T_e')$$

Also

$$h_i = h_A(T_i)$$

Further

$$h_e = h_i + \frac{h_e' - h_i}{\eta_c}$$

From h_e , the temperature T_e is obtained with an iteration of Eq. 15 for $f = 0$.

The driving power of the compressor is

$$HP = \dot{w}_c (h_e - h_i) \frac{J}{550}$$

For the low compressor:

$$\dot{w}_c = \dot{w}_E (1 + b) = \dot{w}$$

$$h_e = h_2$$

$$h_i = h_1$$

$$\eta_c = \eta_{LC}$$

For the high compressor:

$$\dot{w}_c = \dot{w}_E = \dot{w} / (1 + b)$$

$$h_e = h_3$$

$$h_i = h_2$$

$$\eta_c = \eta_{HC}$$

7. HIGH TURBINE CALCULATIONS

The high turbine must drive the high compressor. Hence,

$$(1 - \xi) \dot{w}_E (1 + f_B')(h_4 - h_5) = \dot{w}_E (h_3 - h_2)$$

or

$$h_5 = h_4 - \frac{h_3 - h_2}{(1 - \xi)(1 + f_B')} \quad (21)$$

where the value of f , to calculate h_5 and h_4 , equals f_B' . Equation 14 iterated yields T_5 . With the high turbine efficiency η_{HT} , the isentropic enthalpy h_5' at the high turbine exit is

$$h_5' = h_4 - \frac{h_4 - h_5}{\eta_{HT}} \quad (22)$$

This value of h_5' is used to determine the corresponding isentropic temperature T_5' . Then by Eq. 11

$$\frac{P_5}{P_4} = e^{\left[\frac{J}{R_G} (\varphi_5' - \varphi_4) \right]} \quad (23)$$

The values of φ and R_G must be determined for $f = f_B'$.

8. EXPANSION PROCESS

The pressure ratio in the low turbine is known from Eq. 2, if P_5/P_4 has been determined. The pressure ratio in the jet nozzle is given by Eq. 3. For both processes the same calculating method can be applied; for the low turbine to establish its work output, and for the jet nozzle to determine the discharge velocity V_d .

Let P_i, T_i be the inlet and P_e, T_e the discharge conditions. The temperature T_e' occurs for an isentropic expansion from P_i, T_i to P_e . The gas shall have the fuel/air ratio f . Then, by Eq. 10

$$\varphi_e' = \varphi_i + \frac{R_G}{J} \ln \left(\frac{P_e}{P_i} \right)$$

where the values of φ and R_G depend on f . The value of φ_e' is used to obtain T_e' . For T_e' the enthalpy h_e' is determined from Eq. 14. Then, with the efficiency η_e of the expansion process,

$$h_e = h_i - (h_i - h_e') \eta_e$$

From h_e there is obtained the exit temperature T_e .

9. LOW TURBINE CALCULATIONS

The method of section 7 can be used for the low turbine with:

$$T_i = T_6$$

$$P_e/P_i = P_8/P_5 \quad (\text{Eq. 2})$$

$$f = f_B$$

$$\eta_e = \eta_{LT}$$

to determine $T_e = T_8$ and $h_e = h_8$. The low turbine power is then

$$HP_{LT} = \dot{w}_E (1 + f_B) (h_6 - h_8) \frac{J}{550}$$

Since the low turbine drives the low compressor, there is

$$\dot{w}_E (h_6 - h_8) = \dot{w} (h_2 - h_1) = \dot{w}_E (1 + b) (h_2 - h_1)$$

Hence the bypass ratio b equals

$$b = \frac{(1 + f_B)(h_6 - h_8)}{h_2 - h_1} - 1$$

10. JET NOZZLE DISCHARGE VELOCITY

The method of section 7 can be used to establish the jet nozzle discharge conditions with:

$$T_i = T_9 = T_{10} = T_{11}$$

$$P_e/P_i = P_o/P_{11} = P_{12}/P_{11} \quad (\text{Eq. 3})$$

$$f = f_N \quad (\text{Eq. 11})$$

$$\eta_e = \psi^2$$

where ψ is the velocity coefficient of the nozzle. The static temperature T_{12} and the static pressure P_{12} are equal to T_e and P_e of section 7. The

static enthalpy h_{12} corresponds to h_e , and

$$V_d = \sqrt{2 g J (h_{11} - h_{12})}$$

The Mach number M_d of V_d equals (see section 3)

$$M_d = \frac{V_d}{\sqrt{\frac{g R_G T_{12}}{1 - \frac{R_G T_{12}}{J h_{12}}}}}$$

11. ENGINE PERFORMANCE

The thrust F produced at sea-level static conditions is

$$F = \dot{w}(1 + f_N) \frac{V_d}{g} \quad (\text{lb f})$$

or the so-called specific impulse I_{SP} becomes

$$I_{SP} = \frac{F}{\dot{w}} = \frac{(1 + f_N) V_d}{g} \quad \left(\frac{\text{lb f}}{\text{lb m/s}} \right) \quad (24)$$

The specific fuel consumption is

$$\text{SFC} = \frac{f_N \dot{w}}{F} = \frac{f_N (3600)}{I_{SP}} \quad \left(\frac{\text{lb fuel/hr}}{\text{lb thrust}} \right)$$

12. ENGINE THRUST VS. OUTER DIAMETER OF LOW COMPRESSOR

The calculating program contains an auxiliary part which can be used to determine the engine thrust for a specified outer diameter D_{TL} of the low compressor if it has so-called impulse bladings.

With a chosen hub/tip ratio ahead of the first stage; $r_{hl} = D_{hl}/D_{TL}$, and from the velocity diagram of Fig. 4, or

$$V_1 = U_T \cot \beta_{1T}$$

there is

$$\dot{w} = \frac{\pi}{4} D_{TL}^2 (1 - r_{hl}^2) U_T \cot \beta_{1T} \frac{P_{s1}}{R_G T_{s1}} k_1 \quad (25)$$

where k_1 is a blockage factor to account for the displacement thickness of the wall boundary layers at station 1.

Equation 25 holds for the assumption that the axial velocity V_1 at the low compressor inlet eye area is constant and that it can be calculated from the conditions at the tip diameter where the peripheral speed U_T (ft/s) and the relative flow angle β_{1T} exist. The quantities T_{s1} and P_{s1} are static temperature and pressure, respectively, at station 1 of Fig. 1. The total temperature at 1 equals T_o , or $h_1 = h_o$, and

$$P_1 = (1 - \lambda_I) P_o$$

Then

$$h_{s1} = h_o - \frac{V_1^2}{2g J} = h_o - \frac{(U_T \cot \beta_{1T})^2}{2g J}$$

This equation is similar to Eq. 21. It is possible, therefore, to use the high turbine calculating procedure to establish the static temperature T_{s1} and the static pressure P_{s1} . With

$$(h_4 - h_5) = \frac{(U_T \cot \beta_{1T})^2}{2g J}$$

and

$$\eta_{HT} = 1$$

this procedure gives $T_{s1} = (T_e)$; and $P_{s1}/P_1 = (P_e/P_i)$ for $f = 0$. The values in the brackets shall indicate that their equality pertains only to the correspondence of the values that are obtained from the calculation; to avoid misinterpretation, for instance, that T_{s1} has the same magnitude as the total temperature T_e .

Then

$$P_{s1} = (P_{s1}/P_1) P_1 = (P_{s1}/P_1)(1 - \lambda_I) P_o$$

where P_o must be introduced in psia, if D_{T1} is in inches, to obtain $\dot{w}$ of

Eq. 25 in lbm/s.

The thrust F of the engine is then with Eq. 24,

$$F = \dot{w} I_{SP} \quad (\text{lb}_f)$$

Hence the quantities that must be chosen to obtain $\dot{w}$ and F are D_{T1} , r_{h1} , U_T , β_{1T} and k_1 , in addition to P_O , T_O .

Of interest is also the Mach number M_{W1} of the relative inlet velocity W_{1T} of Fig. 4 at the tip of the rotor blade. From section 3

$$M_{W1} = \frac{W_{1T}}{a_{s1}} = \frac{U_T / \sin \beta_{1T}}{a_{s1}} = \frac{U_T / \sin \beta_{1T}}{\sqrt{\frac{g R_G T_{s1}}{1 - \frac{R_G T_{s1}}{J h_{s1}}}}}$$

Evidently these relations hold only if the first stage of the low compressor is of the impulse type, where a rotor with axial absolute inlet velocity is followed by a stator.

13. CALCULATION PROCEDURE

Programs VA 513 is used to introduce constants and the parameters of the jet engine in the manner listed in the operating instructions of Appendix A. The entered data are printed for checking purposes. Then program VA 514 is read into the calculator. This program calculates the conditions of state at all stations of Fig. 1, and prints the particulars of the different elements of the unit. Subsequently, the overall performance parameters of the engine are printed out, namely, the specific impulse, the specific fuel consumption, the bypass ratio, and the Mach number of the flow at the discharge of the jet nozzle. These quantities are independent of the geometry and the blading particulars of the low compressor at station 1 of Fig. 1.

The program can then process an arbitrary number of sets of low compressor inlet data; that is, diameter, hub/tip ratio, peripheral rotor speed, and

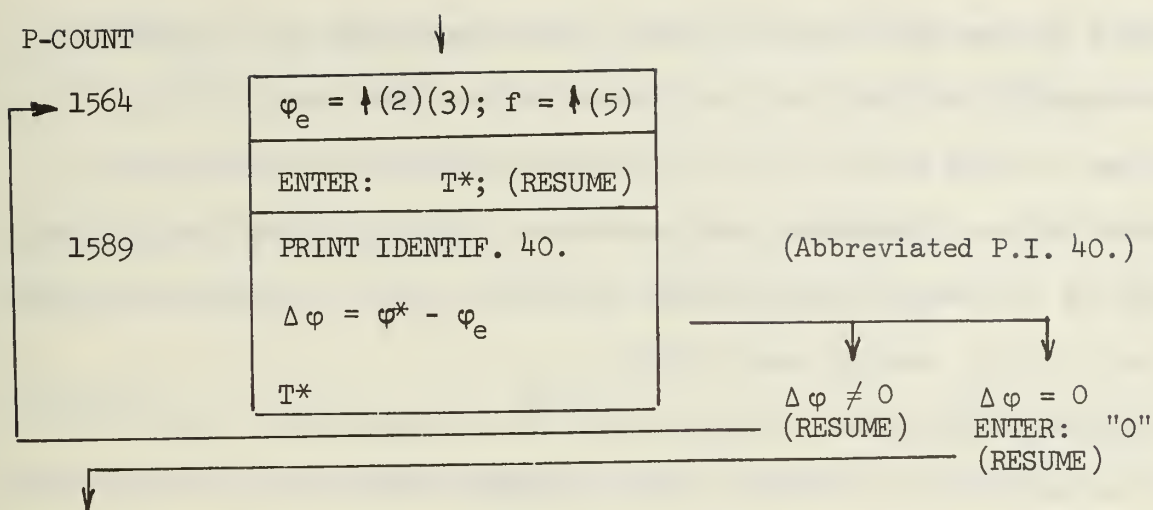
relative tip flow angle of the first stage of the low compressor, to obtain a particular thrust of the jet engine. For these calculations it is assumed that this first stage is of the impulse type as described in section 12. For specified inlet conditions the program prints out the particulars of the turbomachines.

The necessary steps that have to be undertaken by the operator are listed in Appendix A. They consist primarily in trial- and error methods to establish the temperatures at the different stations of the cycle.

These methods of successive approximations are explained in the following.

Let the inlet conditions of an element of the jet engine; that is, of either a compressor or a turbine, be identified by the subscript i , and its discharge conditions by the subscript e (see Fig. 5 for compression process). A similar symbolism will be adopted for the mixing process of Fig. 3, with the difference that the subscripts i and ii are used for the inlet properties of the two gas flows that are mixed. For known inlet conditions the program establishes either the enthalpy h_e of Eq. 14 or the function φ_e of Eq. 14 at the discharge of an element, and the operator must determine the temperature T_e that corresponds to either h_e or φ_e . For given values of h_e or φ_e , the corresponding temperature T_e is also a function of the fuel/air ratio f . For known values of h_e or φ_e , and f , a first approximation of $T_e = T^*$ can be obtained from Figs. 6a, 6b or Figs. 7a, 7b, respectively. If $T^* = T_e$ is entered, the program calculates either $\Delta h = h^* - h_e$, or $\Delta \varphi = \varphi^* - \varphi_e$, where h^* and φ^* are the values of h and φ for T^* and f . Then the quantities Δh , or $\Delta \varphi$, and T^* are printed out, after a print identification number which is left-justified.

In the operating instructions all iterations are indicated by the set-up which is shown below.



In this example the temperature T_e must be established at P-Count 1564 for particular values φ_e and f . The symbol $\uparrow(2)(3)$ indicates that φ_e is stored in data register 32, and $\uparrow(5)$ shows that f is stored in scratch pad register 5. These values can be recalled and printed. Then, a first approximation of $T_e = T^*$ is obtained from Fig. 7 which is entered at P-Count 1564. After depressing the (RESUME) key the calculator will stop at P-Count 1589 to display the print identifier (40.), the difference $\Delta\varphi = \varphi^* - \varphi_e$, and the value of T^* which was entered at P-Count 1564. The quantity φ^* in $\Delta\varphi$ is the value of φ that corresponds to T^* and f , whereas φ_e is the value for which T_e has to be determined. If the error $\Delta\varphi$ is excessive, the (RESUME) key must be depressed to return the calculations to P-Count 1564, where a better approximation for $T^* = T_e$ can be entered, namely, smaller values if $\Delta\varphi$ was negative. This process is repeated as often as necessary until the error $\Delta\varphi$ has been reduced to acceptable values. Then a zero (0) must be entered on the keyboard before the (RESUME) key is depressed. With this manipulation the program leaves the iteration loop and continues with the subsequent calculations.

Iterations of T_e for known values of h_e and f follow the same pattern, with the exception that $\Delta h = h^* - h_e$ is displayed instead of $\Delta\varphi$. If it is assumed that the temperatures T_e to be determined deviate by not more

± 0.005 $^{\circ}\text{R}$ from their correct values, the error $\Delta\phi$ should not exceed about $3(10^{-6})$, and the error Δh should be less than about $2(10^{-3})$. The program sets the decimal point to six, hence all print-outs have six decimal digits. Therefore, the iterations of T_e for ϕ_e must be continued until $\Delta\phi$ is smaller than 0.000003, and those of T_e for h_e must be repeated until Δh is smaller than 0.00200.

During the execution of the program the so-called print-outs A occur for the compressors, turbines, and the exhaust nozzle and inlet duct. The form of print-out A is as follows:

Identifier (left-justified, negative number in red)

P_e/P_i = exit pressure/inlet pressure

T_i = inlet temperature ($^{\circ}\text{R}$)

h_i = inlet enthalpy (Btu/lbm)

η = efficiency of process

T_e = exit temperature ($^{\circ}\text{R}$)

h_e = exit enthalpy (Btu/lbm)

$h_e - h_i$ or $h_i - h_e$ (positive value)

f = fuel/air ratio

$\bar{\gamma}$ = average value of $\gamma = c_p/c_v$ for isentropic process from

P_i, T_i to P_e

R_G = gas constant $\left(\frac{\text{ft} - \text{lb}}{\text{lbm}, ^{\circ}\text{R}} \right)$

For the turbomachines the values of P_e , P_i , T_i , h_i , T_e , h_e correspond to the total conditions at inlet and exit. For the exhaust nozzle and the inlet duct the pressure P_e , the temperature T_e and the enthalpy h_e pertain to the static conditions at the exit, and $h_i - h_e$ equals the kinetic energy

$V_e^2/2gJ$ where V_e is the actual velocity at the exit of the exhaust nozzle N at station 12 of Fig. 1; or ahead of the blading of the low compressor at station 1 of Fig. 1 for the inlet duct I.

The identifier preceding print-out A is indicative of the element to which the results pertain. In the following table this correspondence is listed.

Identifier	Element	Inlet and Exit Stations of Fig. 1 (i) - (e)
- 101.	Inlet Nozzle	0 - 1
- 12.	Low Compressor	1 - 2
- 23.	High Compressor	2 - 3
- 45.	High Turbine	4 - 5
- 68.	Low Turbine	6 - 8
- 1,112.	Exhaust Nozzle	11 - 12

The results of the combustion processes are given with the so-called print-outs B, which have the following form:

Identifier (left-justified, negative number in red)

T_e = exit temperature ($^{\circ}R$)

h_e = exit enthalpy (Btu/lbm)

Δf = fuel added in combustor per pound of mixture

f_e = fuel/air ratio at exit of combustor.

The so-called print-out C displays the result of a mixing process as follows:

Identifier (left-justified, negative number in red)

T_e = temperature after mixing ($^{\circ}R$)

h_e = enthalpy after mixing (Btu/lbm)

$\zeta = \dot{w}_{ii}/\dot{w}_i$ = ratio of flow rates of gases to be mixed

f_e = fuel/air ratio after mixing

In print-outs B and C the identifier has the form -7xx, where xx is indicative of the index of the exit station, in accordance with Fig. 1, of either the combustor, or the station where the mixing has occurred. Thus, the identifier -704. refers to the conditions at station 4 after the main burner, and -711 is indicative of station 11 of Fig. 1 after the gas flows from the duct and afterburner have been mixed.

Identifiers and/or print-outs that do not correspond to the above-mentioned categories are explained in Appendix A.

The program can be used also for jet engines without reheat by duct burner and afterburner. Appendix B gives the operating instructions for such units.

The complete listing of the calculating steps of programs VA 513 and VA 514 is given in Appendix C together with forms that show the contents of the scratch pad and main data registers.

14. EXAMPLES

Two examples are given which can be used to check the program. Example A deals with a jet engine with afterburner which may be classified as a second generation unit for the propulsion of air-superiority aircraft of the F-14 type. It operates with turbine inlet temperatures of 2900 °R (2540 °F) and has an overall pressure ratio P_3/P_1 of 30. Its diameter at the low compressor inlet is 36 inches, equal to that of the F401 engine presently in development for the F-14B aircraft (see Ref. 3).

Tables I(1) and I(2) give the results of the calculations. These tables are of standard form to which the print-outs of the program are attached. Table I(2) shows that the thrust of the unit can be increased from 28,563 pound to 32,618 pound by increasing the tip speed of the rotor

Ref. 3 Aviation Week & Space Technology, Vol. 96, No. 26, June 26, 1972, pp. 88/97.

of the first stage of the low compressor from 1600 ft/s to 1700 ft/s, and by decreasing its hub/tip ratio from 0.4 to 0.35. However the higher tip speed increases the tip Mach number of the relative flow of the first compressor stage from about 1.65 to 1.91. The bypass ratio is $b = 0.88$ for both cases.

The following list gives the temperatures which were determined by the iterations in Example A to make possible a quick check of the program on the Monroe calculator. Indicated are the P-Counts, in the same order as they occur in the calculating sequence, and the errors, in either $\Delta \varphi$ or Δh .

<u>P-Count</u>	<u>ENTRY: T*</u>	<u>PRINT-OUT:</u>
1213	$T_2' = 742.015$	$\Delta \varphi = 0.000\ 000$
1272	$T_2 = 777.813$	$\Delta h = -0.000\ 013$
1213	$T_3' = 1397.775$	$\Delta \varphi = 0.000\ 000$
1272	$T_3 = 1479.194$	$\Delta h = 0.000\ 020$
1567	$T_5 = 2295.791$	$\Delta h = -0.000\ 079$
1628	$T_5' = 2203.423$	$\Delta h = 0.000\ 016$
1933	$T_6 = 2258.783$	$\Delta h = -0.000\ 092$
1361	$T_8' = 1818.390$	$\Delta \varphi = 0.000\ 000$
1419(*)	$T_8 = 1863.262$	$\Delta h = 0.000\ 003$
1361	$T_{12}' = 2655.945$	$\Delta \varphi = 0.000\ 000$
1419	$T_{12} = 2700.647$	$\Delta h = 0.000\ 027$

For data (1) of Table I(1) of the first-stage rotor of the low compressor, the obtained temperatures are:

<u>P-Count</u>	<u>ENTRY: T*</u>	<u>PRINT-OUT:</u>
1567	$T_1 = 473.629$	$\Delta h = -0.000\ 056$

For data (2) of Table I(1)

1567	$T_1 = 439.692$	$\Delta h = 0.000\ 033.$
------	-----------------	--------------------------

Example B deals with the same engine as Example A but without reheat by duct and afterburner. These elements are supposed to be installed however so that their pressure drops are taken into account. Tables II(1) and II(2) give the results of the calculations. With data (1) of the first-stage of the low compressor, the thrust is 17,309 pounds, and with data (2) it becomes 19,766 pound. Hence, reheat to 3400 °R (2940 °F) increases the thrust by about 11,200 to 12,800 pound, but the specific fuel consumption is increased from 0.676 lb fuel/(lb thrust, hour) to a value of 1.691.

To check out Example B on the calculator without iterations, the same temperatures must be introduced as given in the preceding list for Example A, up to and including P-Count 1419 that is marked with an asterisk (iteration of T_8). The subsequent entries are:

<u>P-Count</u>	<u>ENTRY: T*</u>	<u>PRINT-OUT:</u>
1933	$T_{11} = 1387.086$	$\Delta h = -0.000\ 014$
1361	$T_{12}' = 1020.635$	$\Delta \varphi = 0.000\ 000$
1419	$T_{12} = 1042.728$	$\Delta h = -0.000\ 059$

For data (1) and (2) of the first-stage rotor of the low compressor of Table II(1), the temperatures to be introduced at P-Count 1567 are $T_1 = 473.629$ and $T_1 = 439.692$, respectively, as for Example A.

INPUT DATA
(GENERAL)

.....
-100.
14.7000
520.0000
3.5000
30.0000
2,900.0000
3,400.0000
0.0500
0.0100
0.0200
0.0500
0.0600
0.8600
0.8800
0.8700
0.9000
0.9600
0.9300
0.9700
.....
P0
T0
P2/P1
P3/P1
T4
T9-T10
F
λI
λBP
λB
λAB
ηLC
ηHC
ηHT
ηLT
ηB
ηAB
↓

CALCULATED PERFORMANCE DATA

.....
-200.
109.976328
1.691403
0.880183
1.355328
.....
ISP
SFC
b
Md

CHOSEN DATA OF FIRST-STAGE ROTOR OF LOW COMPRESSOR
(1)

INLET DUCT

-101.
0.721370
520.000000
124.288220
1.000000
473.629000
113.171386
11.116834
0.000000
1.400536
53.351334
.....
Psl/P1
T1
h1
η
Tsl
hsl
h1-hsl
f
γ
RG

ENGINE DATA (1)

-300.
36.000000
0.400000
1,600.000000
65.000000
0.980000
28,563.000000
259.728519
22,927.000000
34,710.000000
1.653353
.....
DT1
rhl
UT
βIT
kl
F
w
HP_{LC}
HP_{HC}
Mw1

INLET DUCT

-101.
0.556480
520.000000
124.288220
1.000000
439.692000
105.049657
19.238563
0.000000
1.400972
53.351334
.....
Psl/P1
T1
h1
η
Tsl
hsl
h1-hsl
f
γ
RG

ENGINE DATA (2)

-300.
36.000000
0.350000
1,700.000000
60.000000
0.980000
32,618.000000
296.595808
26,182.000000
39,637.000000
1.907981
.....
DT1
rhl
UT
βIT
kl
F
w
HP_{LC}
HP_{HC}
Mw1

TABLE I(1) JET ENGINE (WITH) (WITHOUT) AFTERBURNER ; PROG. VA 513/514

CONFIGURATION EXAMPLE A FORM 1 of 2;

TABLE I(2) JET ENGINE DATA (WITH) (WITHOUT) AFTERBURNER.; PROG. VA 513/514.
CONFIGURATION EXAMPLE A FORM 2 of 2;

LOW COMPRESSOR			HIGH COMPRESSOR			HIGH TURBINE			EXIT AFTERBURNER		
-12.			-23.			-45.			-710.		
P ₂ /P ₁	3.500000		P ₃ /P ₂	8.571429		P ₅ /P ₄	0.299998		T ₁₀	3,400.000000	
T ₁	520.000000		T ₂	777.813000		T ₄	2,900.000000		h ₁₀	982.361522	
h ₁	124.288220		h ₂	186.680734		h ₄	788.603825		Δf	0.031388	
η _{LC}	0.860000		η _{HC}	0.880000		η _{HT}	0.870000		f ₁₀	0.054913	
T ₂	777.813000		T ₃	1,479.194000		T ₅	2,295.791000		EXIT DUCT BURNER		
h ₂	186.680747		h ₃	364.277862		h ₅	606.176939		.....	.....	
h ₂ -h ₁	62.392527		h ₃ -h ₂	177.597128		h ₄ -h ₅	182.426886		-709.		
f	0.000000		f	0.000000		f	0.024763		3,400.000000		
γ	1.396268		γ	1.396268		γ	1.295604		973.588906		
R _G	53.351334		R _G	53.351334		R _G	53.393384		0.047987		
.....			.....			.....			0.047987		
HIGH COMPRESSOR			HIGH COMPRESSOR			INLET LOW TURBINE			INLET JET NOZZLE		
-23.			-23.			-706.			-711.		
P ₃ /P ₂	8.571429		T ₆	2,258.783000		T ₉	2,258.783000		3,400.000000		
T ₂	777.813000		h ₆	594.359904		h ₉	594.359904		978.269121		
h ₂	186.680734		G-E/(1-5)	0.052632		Δf	0.052632		0.880183		
η _{HC}	0.880000		f ₆	0.023525		f	0.023525		0.051671		
T ₃	1,479.194000		.....			.....			.....	.....	
h ₃	364.277862		LOW TURBINE			.....			EXPANSION JET NOZZLE	.....	
h ₃ -h ₂	177.597128		-68.			-68.			-1,112.		
f	0.000000		P ₈ /P ₆	0.401172		P ₁₂ /P ₁₁	0.401172		0.313287		
γ	1.375188		T ₆	2,258.783000		T ₁₁	2,258.783000		3,400.000000		
R _G	53.351334		h ₆	594.359812		h ₁₁	594.359812		978.269121		
.....			η _{LT}	0.900000		η _N	0.900000		0.940900		
EXIT MAIN BURNER			T ₈	1,863.262000		T ₁₂	1,863.262000		2,700.647000		
-704.			h ₈	479.746692		h ₁₂	479.746692		752.197995		
T ₄	2,900.000000		h ₆ -h ₈	114.613120		h ₁₁ -h ₁₂	114.613120		226.071126		
h ₄	788.603825		f	0.023525		f	0.023525		0.051671		
Δf	0.024763		γ	1.311382		γ	1.311382		1.270314		
f ₄	0.024763		R _G	53.391330		R _G	53.391330		53.436831		
.....											

TABLE II(1) JET ENGINE (~~WITH~~) (WITHOUT) AFTERBURNER ; PROG. VA 513/514

CONFIGURATION EXAMPLE B FORM 1 of 2;

INPUT DATA (GENERAL)		CHOSEN DATA OF FIRST-STAGE ROTOR OF LOW COMPRESSOR (1)		INLET DUCT		ENGINE DATA (1)		INLET DUCT		ENGINE DATA (2)	
P ₀	14.7000	-100.	P _{sl} /P ₁	-101.	0.721370	0.721370	0.556480	-101.	0.556480	36.000000	36.000000
T ₀	520.0000		T ₁	520.000000	520.000000	520.000000	520.000000	520.000000	520.000000	0.350000	0.350000
P ₂ /P ₁	3.5000		h ₁	124.288220	124.288220	124.288220	124.288220	124.288220	124.288220	1.700.000000	1.700.000000
P ₃ /P ₁	30.0000		η	1.000000	1.000000	1.000000	1.000000	1.000000	1.000000	60.000000	60.000000
T ₄	2900.0000		T _{sl}	473.629000	473.629000	473.629000	473.629000	473.629000	473.629000	0.980000	0.980000
T _{9-T₁₀}	0.0000		h _{sl}	113.171386	113.171386	113.171386	113.171386	113.171386	113.171386	19.766.000000	19.766.000000
ξ	0.0500		h _{1-h_{sl}}	11.1116834	11.1116834	11.1116834	11.1116834	11.1116834	11.1116834	296.595808	296.595808
λ _I	0.0100		f	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	26.182.000000	26.182.000000
λ _{BP}	0.0200		γ	1.400536	1.400536	1.400536	1.400536	1.400536	1.400536	39.637.000000	39.637.000000
λ _B	0.0500		R _G	53.351334	53.351334	53.351334	53.351334	53.351334	53.351334	1.907981	1.907981
λ _{AB}	0.0600										
η _{LC}	0.8600										
η _{HC}	0.8800										
η _{HT}	0.8700										
η _{LT}	0.9000										
η _B	0.9600										
η _{AB}	1.0000										
ψ	0.9700										
CALCULATED PERFORMANCE DATA											
I _{SP}	66.645600	-200.	D _{T1}	-300.	36.000000	36.000000	36.000000	-300.	36.000000	19.766.000000	19.766.000000
SFC	0.675865		r _{h1}	0.400000	0.400000	0.400000	0.400000	0.400000	0.400000	296.595808	296.595808
b	0.880183		U _T	1.600.000000	1.600.000000	1.600.000000	1.600.000000	1.700.000000	1.700.000000	26.182.000000	26.182.000000
M _d	1.342137		β _{1T}	65.000000	65.000000	65.000000	65.000000	60.000000	60.000000	39.637.000000	39.637.000000
			k ₁	0.980000	0.980000	0.980000	0.980000	0.980000	0.980000	1.907981	1.907981
			F	17.309.000000	17.309.000000	17.309.000000	17.309.000000	19.766.000000	19.766.000000		
			ψ	259.728519	259.728519	259.728519	259.728519	296.595808	296.595808		
			HP _{LC}	22.927.000000	22.927.000000	22.927.000000	22.927.000000	26.182.000000	26.182.000000		
			HP _{HC}	34.710.000000	34.710.000000	34.710.000000	34.710.000000	39.637.000000	39.637.000000		
			M _{w1}	1.653353	1.653353	1.653353	1.653353	1.907981	1.907981		

TABLE I(2) JET ENGINE DATA (WITH) (WITHOUT) AFTERBURNER.; PROG. VA 513/514.
CONFIGURATION EXAMPLE B FORM 2 of 2;

LOW COMPRESSOR			HIGH TURBINE			EXIT AFTERBURNER		
P_2/P_1	-12.		P_5/P_4	-45.		T_{10}	-710.	
T_1	3.500000		T_4	0.299998		h_{10}	1,863.262000	
h_1	520.000000		h_4	2,900.000000		Δf	479.746695	
η_{LC}	124.288220		η_{HT}	788.603825		f_{10}	0.000000	
T_2	0.860000		T_5	0.870000			0.023525	
h_2	777.813000		h_5	2,295.791000			.....	
h_2-h_1	186.680747		h_4-h_5	606.176939		EXIT DUCT BURNER		
f	62.392527		f	182.426886		-709.		
γ	0.000000		γ	0.024763		T_9	777.813000	
R_G	1.396268		R_G	1.295604		h_9	186.680734	
	53.351334			53.393384		Δf	0.000000	
	.....			.....		f_9	0.000000	
HIGH COMPRESSOR			INLET LOW TURBINE			INLET JET NOZZLE		
P_3/P_2	-23.		T_6	-706.		-711.		
T_2	8.571429		h_6	2,258.783000		1,387.086000		
h_2	777.813000		$G=5/(1-5)$	594.359904		344.247063		
η_{HC}	186.680734		f_6	0.052632		0.880183		
T_3	0.880000			0.023525		0.012512		
h_3	1,479.194000			.....		.....		
h_3-h_2	364.277862		LOW TURBINE			EXPANSION JET NOZZLE		
f	177.597128			-68.		-1,112.		
γ	0.000000			0.401172		0.313287		
R_G	1.375188			2,258.783000		1,387.086000		
	53.351334			594.359812		344.247049		
	.....			0.900000		0.940900		
EXIT MAIN BURNER				1,863.262000		1,042.728000		
T_4	-704.			479.746692		254.679907		
h_4	2,900.000000			114.613120		89.567142		
Δf	788.603825			0.023525		0.012512		
f_4	0.024763			1.311382		1.359289		
	0.024763			53.391330		53.372837		
								

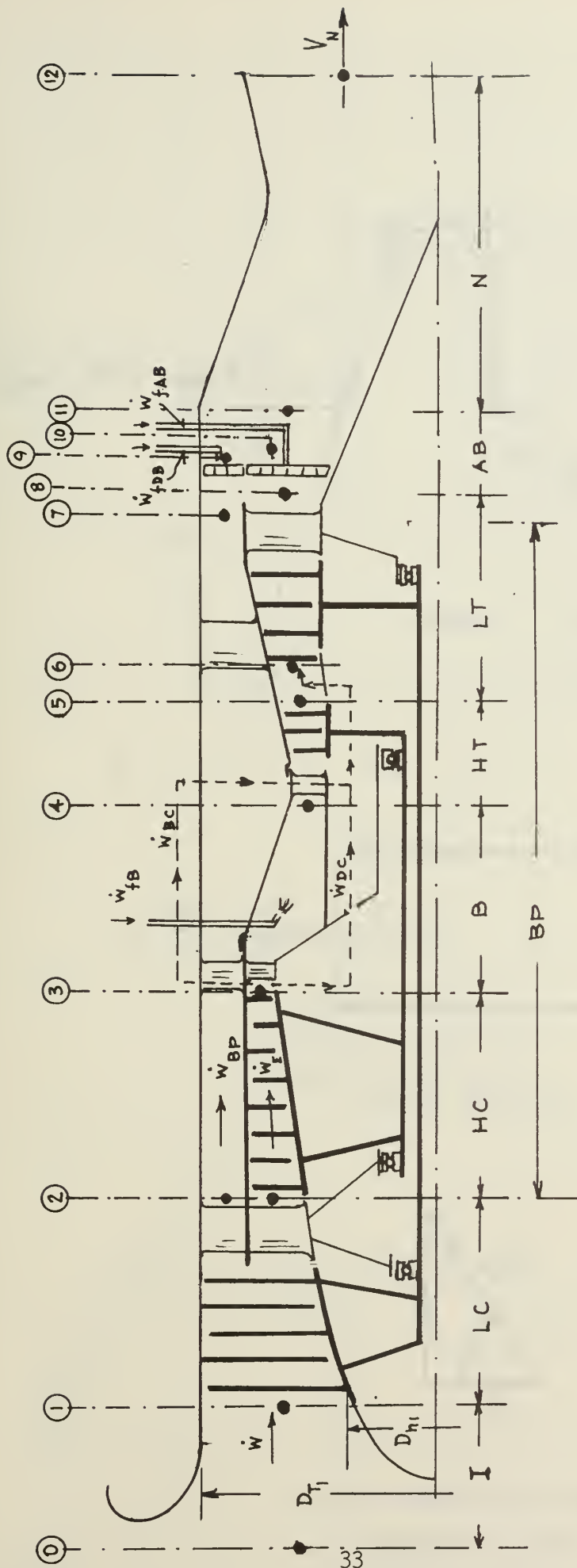


FIG. 1 SCHEMATIC OF BYPASS JET ENGINE WITH DUCT AND AFTERBURNER

I = Inlet Nozzle for Sea Level Static Tests

N = Jet Nozzle with Complete Expansion to $P_0 = P_{12}$

BP = Bypass Duct

B = Main Burner

AB = Duct and Afterburner

LC = Low Compressor

LT = Low Turbine

; HC = High Compressor

; HT = High Turbine

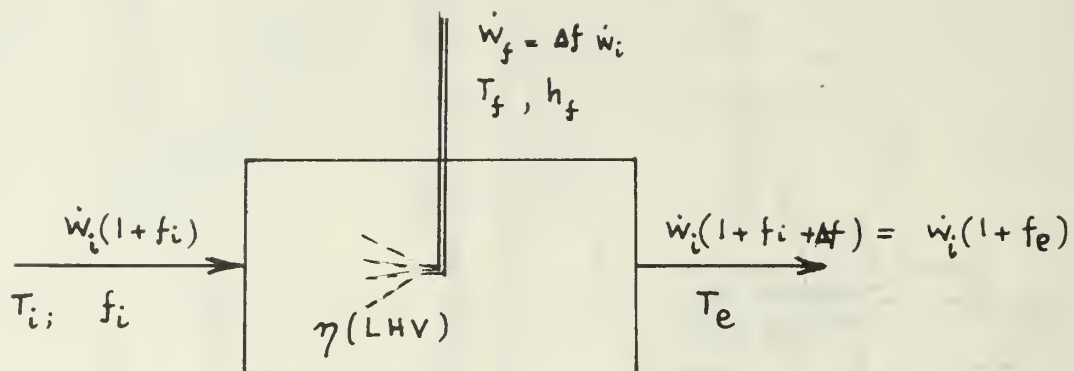


FIG. 2 COMBUSTOR

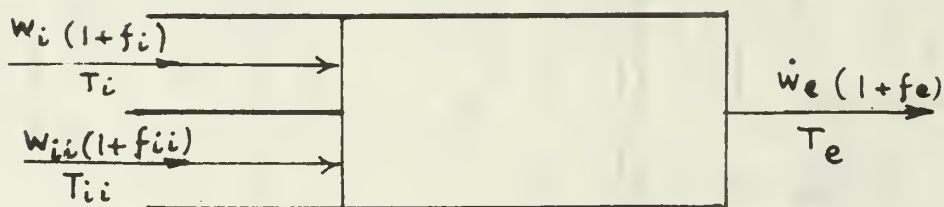


FIG. 3 MIXING PROCESS

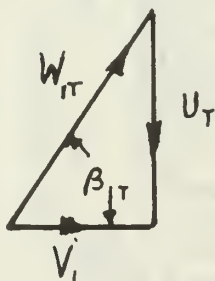


FIG. 4 VELOCITY DIAGRAM AT TIP
OF LOW COMPRESSOR

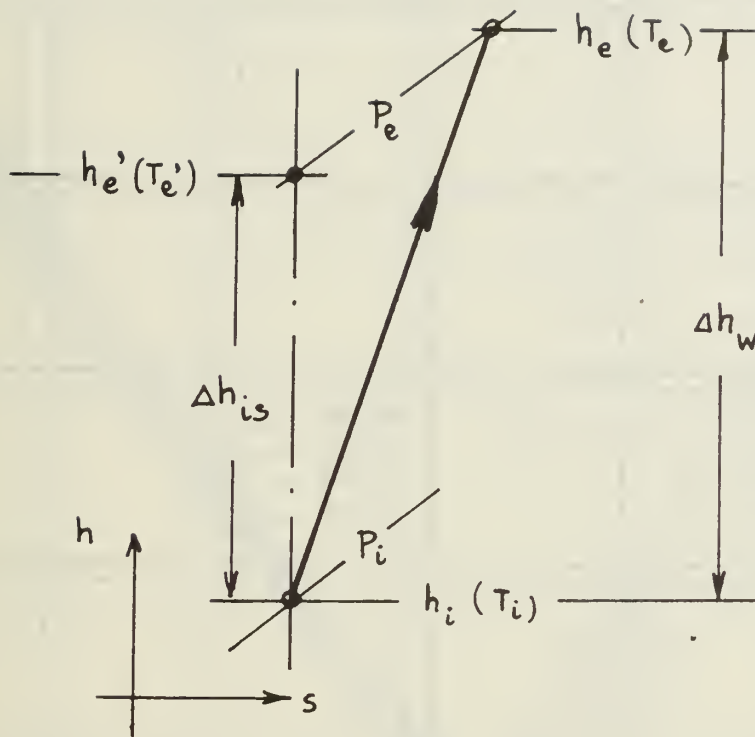
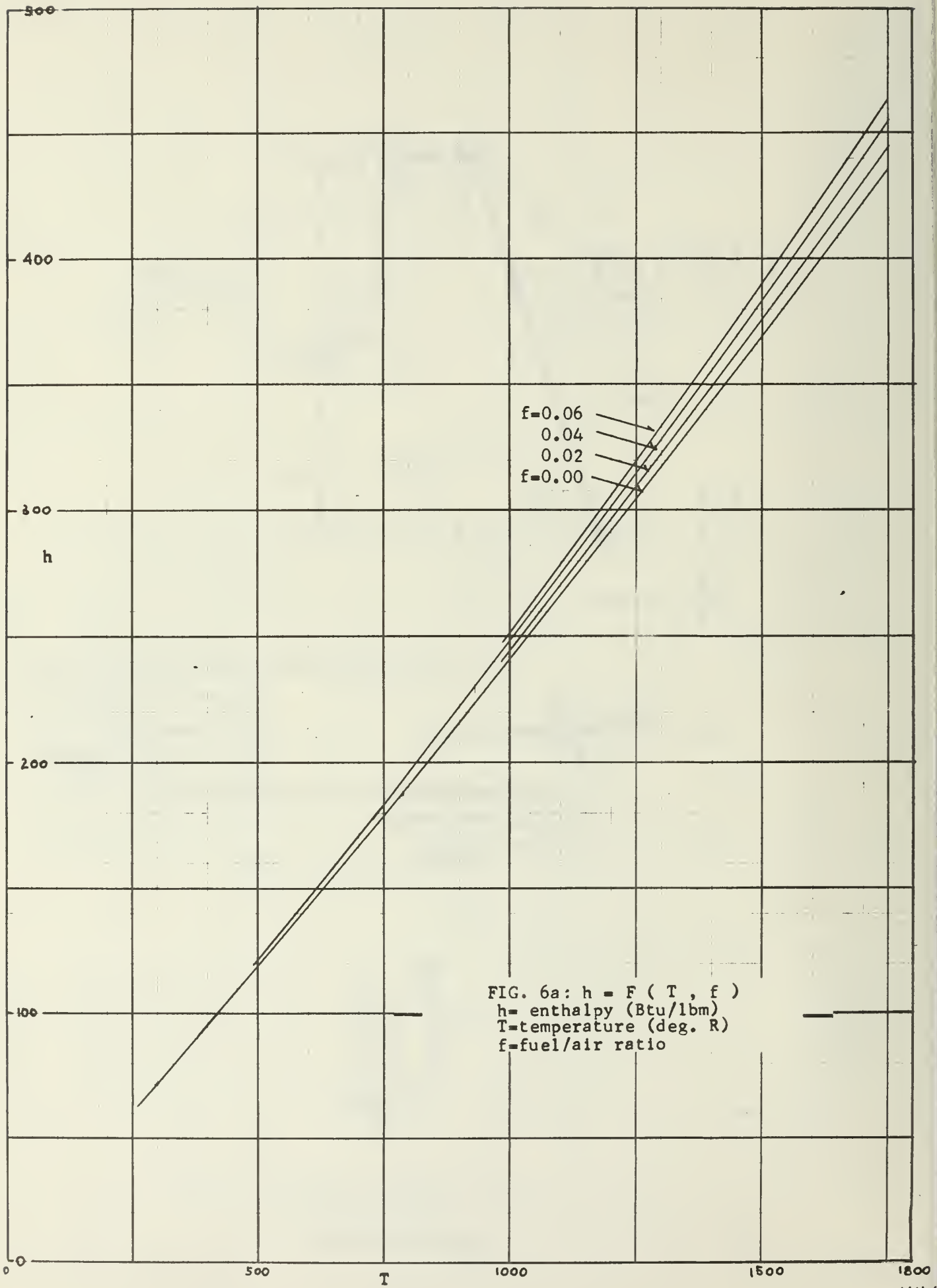
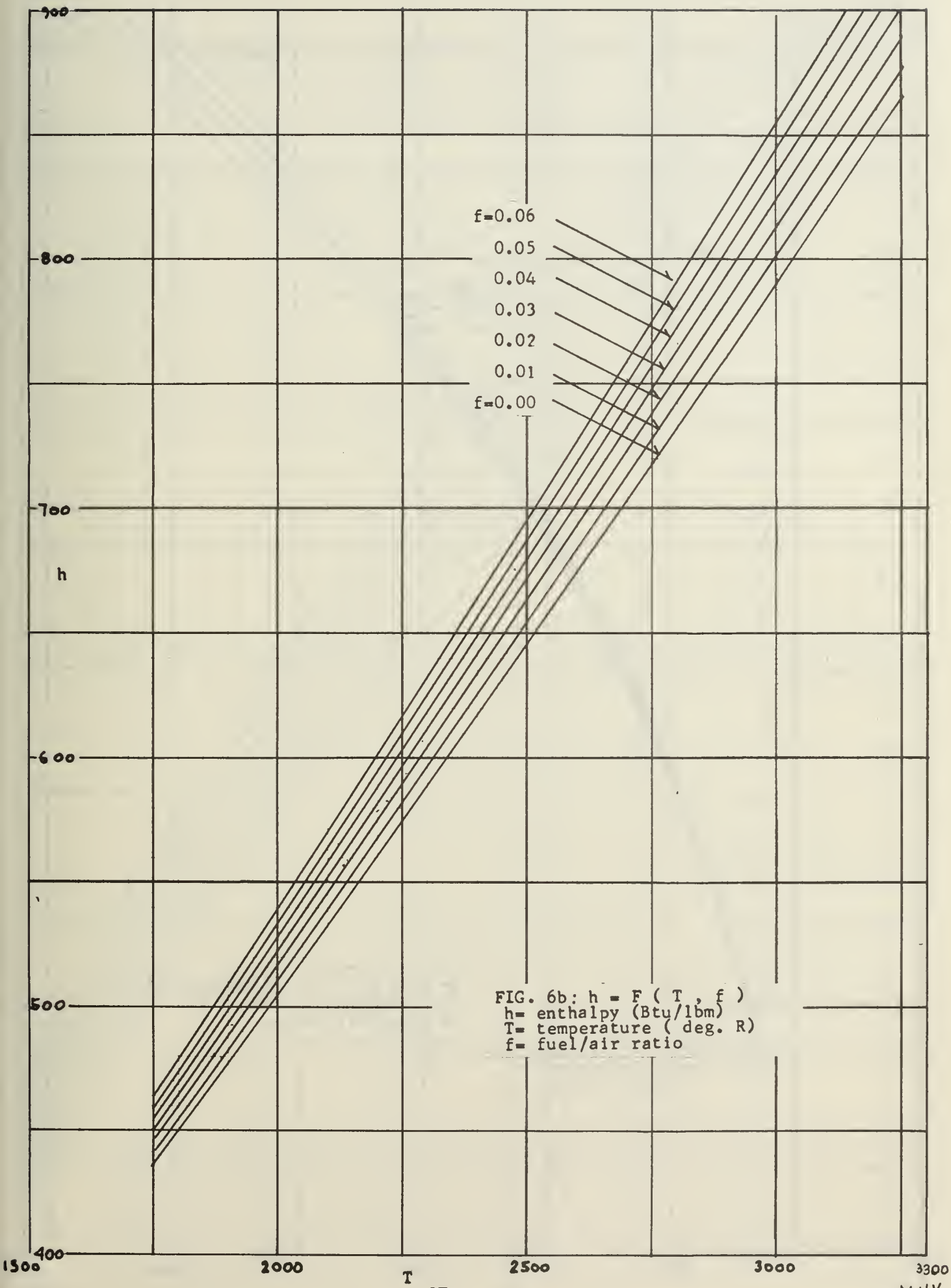


FIG. 5 COMPRESSOR PROCESS

h = total enthalpy
 T = total temperature
 P = total pressure





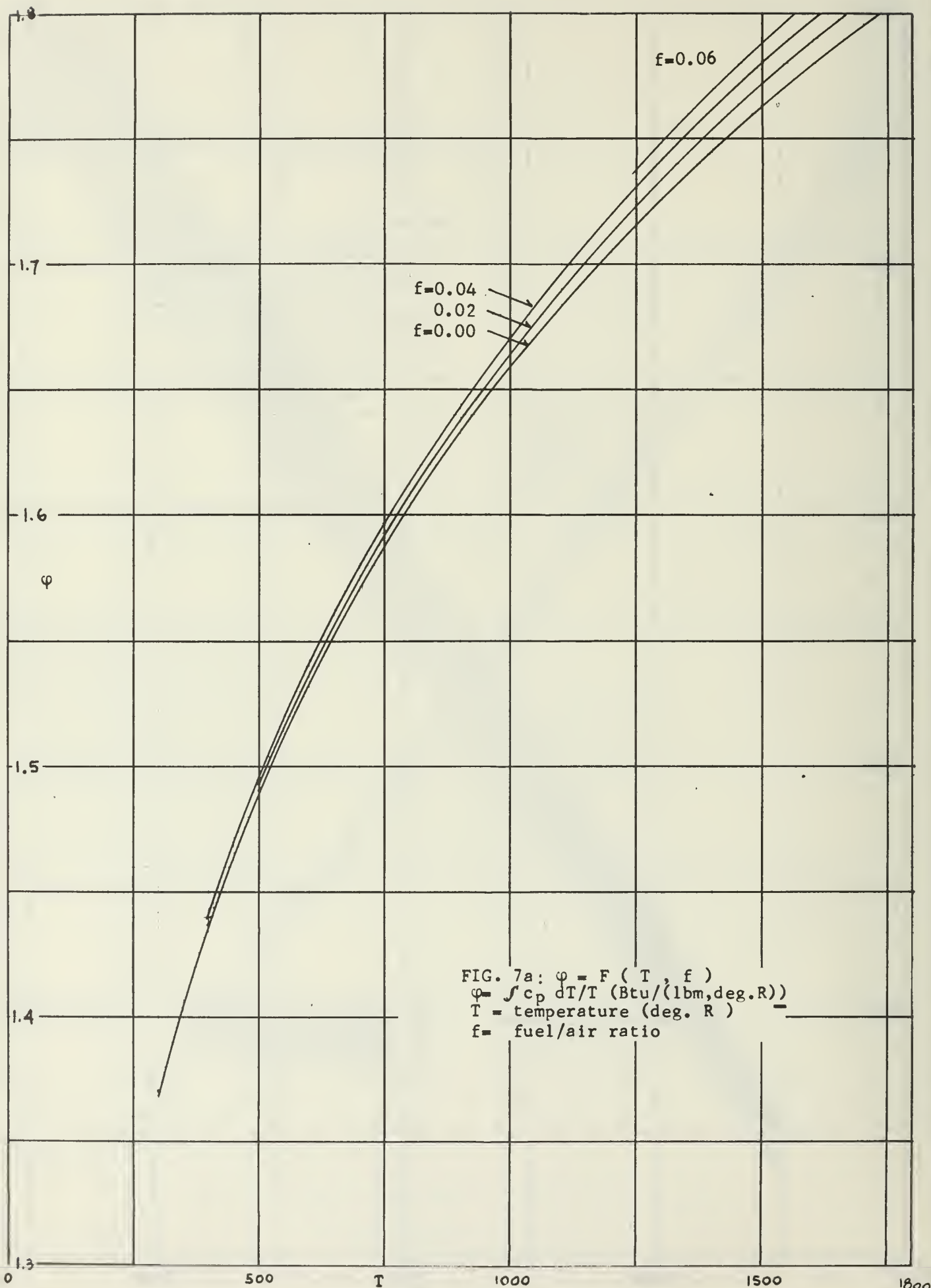
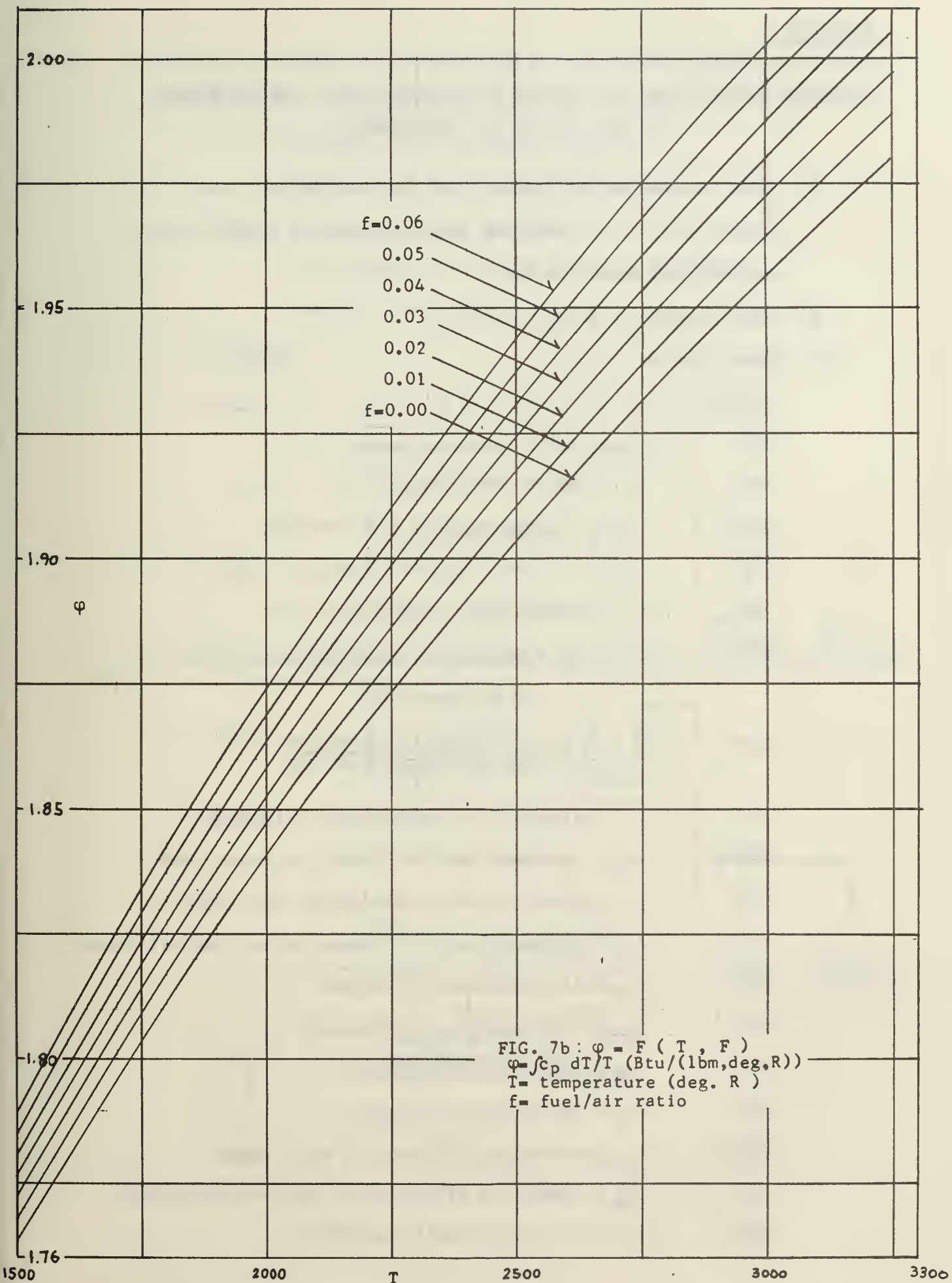


FIG. 7a: $\phi = F(T, f)$
 $\phi = \int c_p dT/T$ (Btu/(lbm, deg. R))
 T = temperature (deg. R)
 f = fuel/air ratio



APPENDIX A

OPERATING INSTRUCTIONS OF PROGRAMS VA 513 AND VA 514 FOR JET ENGINE WITH DUCT BURNER AND AFTERBURNER

- a) Enter Program VA 513 (Sides A and B of one magnetic card) at Branch Point 00. (SENSE and PRINT Switches in "down" position, and GRAD/DEG Switch at DEG)
- b) Start Program at Branch Point 00.
- c) Enter Data

P-COUNT

- 0211 P_O = ambient pressure (psia)
- 0215 T_O = ambient temperature ($^{\circ}R$)
- 0219 P_2/P_1 = pressure ratio low compressor
- 0223 P_3/P_1 = overall compressor pressure ratio
- 0227 T_4 = turbine inlet temperature ($^{\circ}R$)
- 0231 $T_9 = T_{10}$ = temperature after afterburner and duct burner ($^{\circ}R$)
- 0235 $\xi = \frac{\dot{w}_c}{\dot{w}_E} = \frac{\text{Cooling air flow rate}}{\text{High compressor flow rate}}$
- 0239 λ_I = pressure loss coefficient in inlet duct
- 0243 λ_{BP} = pressure loss coefficient in bypass duct
- 0247 λ_B = pressure loss coefficient in main burner
- 0251 λ_{AB} = pressure loss coefficient in duct and afterburner
- 0255 η_{LC} = low compressor efficiency
- 0259 η_{HC} = high compressor efficiency
- 0263 η_{HT} = high turbine efficiency
- 0267 η_{LT} = low turbine efficiency
- 0271 η_B = combustion efficiency of main burner
- 0275 η_{AB} = combustion efficiency of duct and afterburner
- 0279 ψ = jet nozzle velocity coefficient

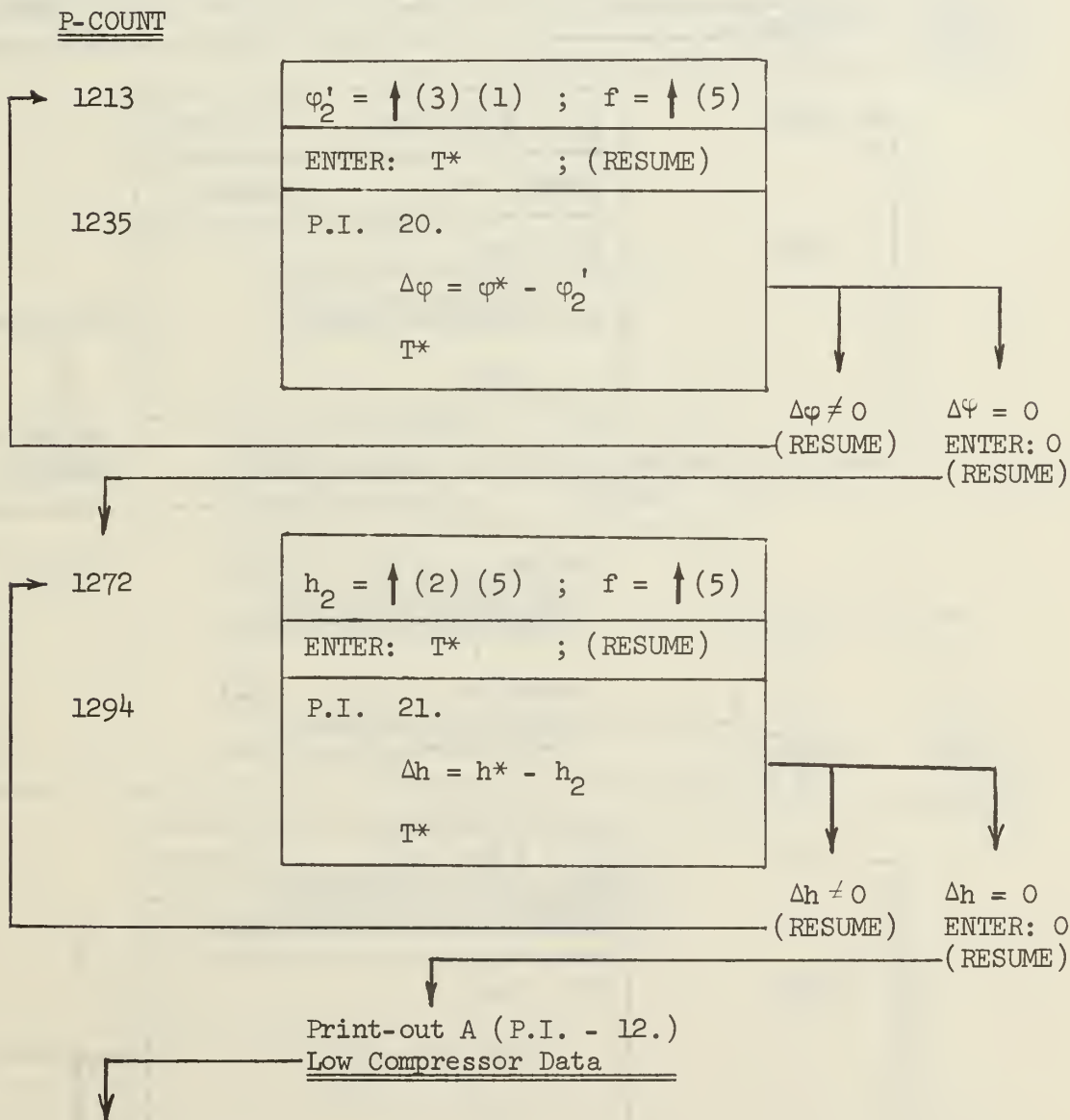
After the last entry the program prints out the above data, in the order listed, with the print identifier - 100.

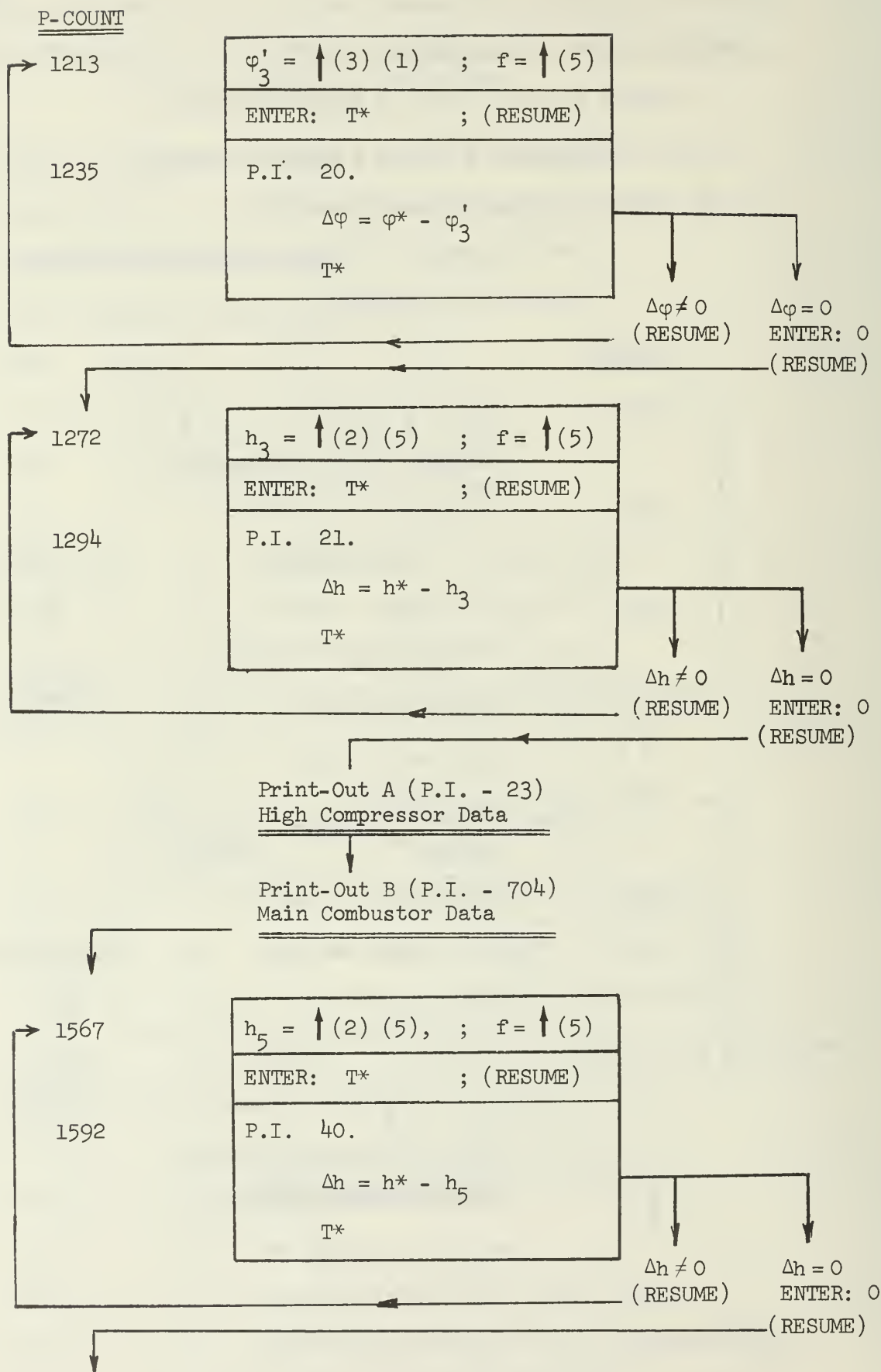
d) Enter Program VA 514 at Branch Point 00.

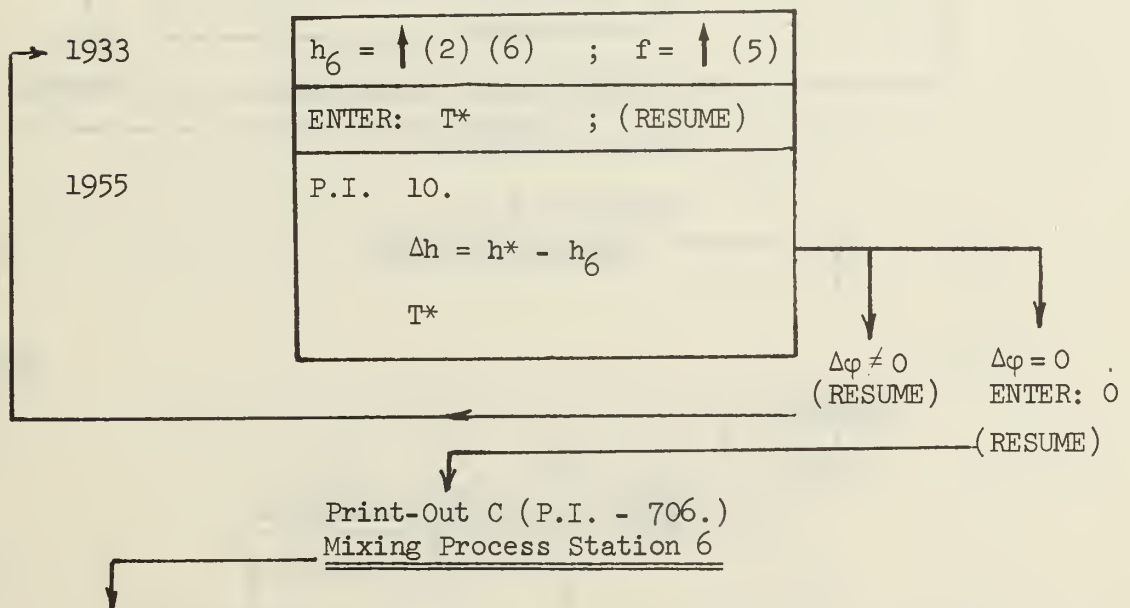
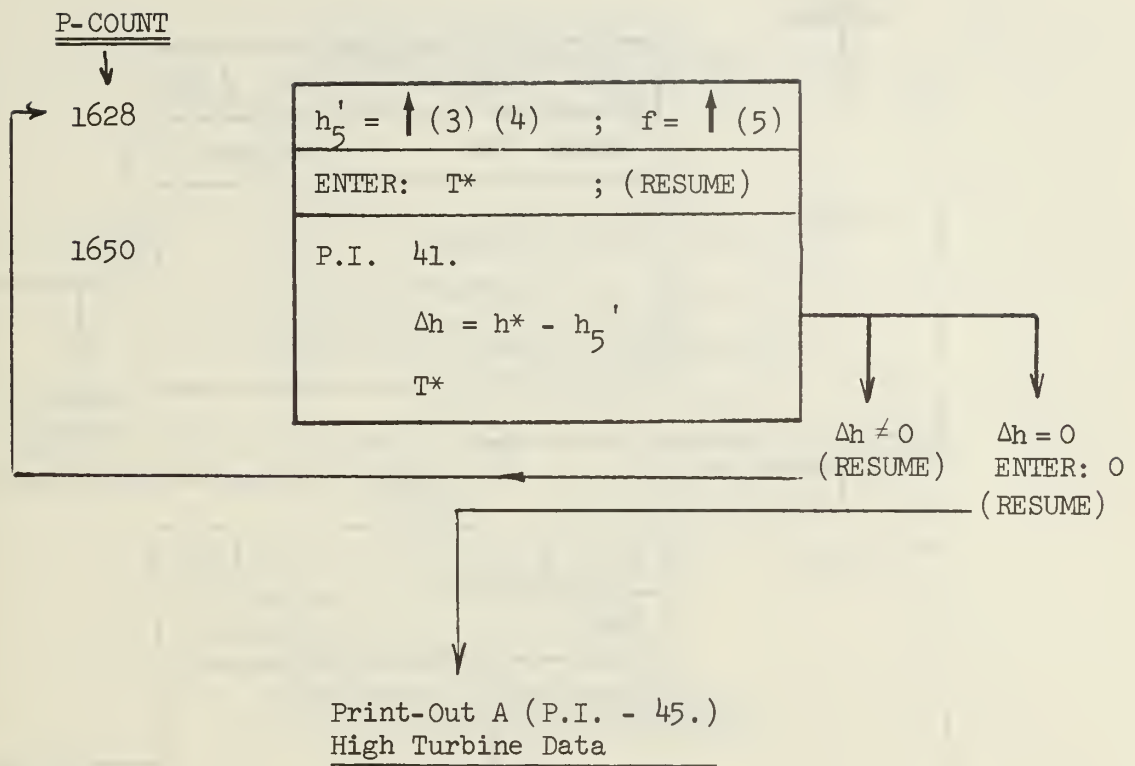
(Sides A and B of 4 magnetic cards)

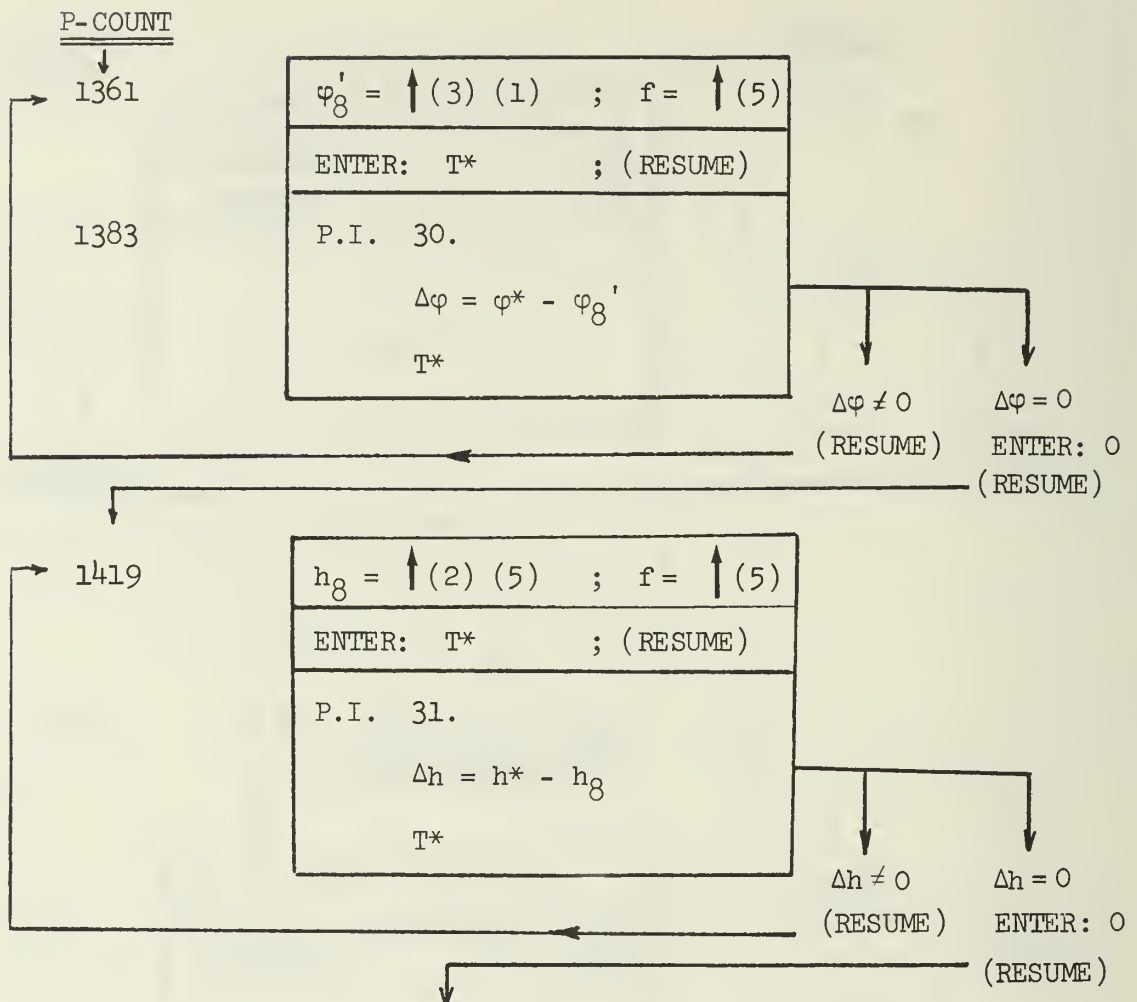
e) Start Program at Branch Point 00

(For explanation of the iteration procedure see section 13 of report)









Print-Out A(P.I. -68.)
Low Turbine Data

P-COUNT
↓
0332

P.I. -700.
Print-Out of Bypass Ratio b

If b is ok
(RESUME)

If b is not ok
start with new
data at Step a)

Print-Out B(P.I. -710.)
Conditions after Afterburner

Station 10 of Fig. 1

0376 Check of maximum fuel/air ratio f_{10}
 after afterburner (last value of
 above print-out P.I. -710.)

If f_{10} is ok
 (RESUME)

If f_{10} is too large
 start with new data
 at step a.)

Print-Out B(P.I. -709.)
Conditions after Duct Burner

Print-Out C(P.I. -711.)

Conditions at Station 11
 Mixed Duct Burner and
 Afterburner Flows

P-COUNT

1361

1383

$\varphi_{12}' = \uparrow(3) (1) ; f = \uparrow(5)$

ENTER: T^* ; (RESUME)

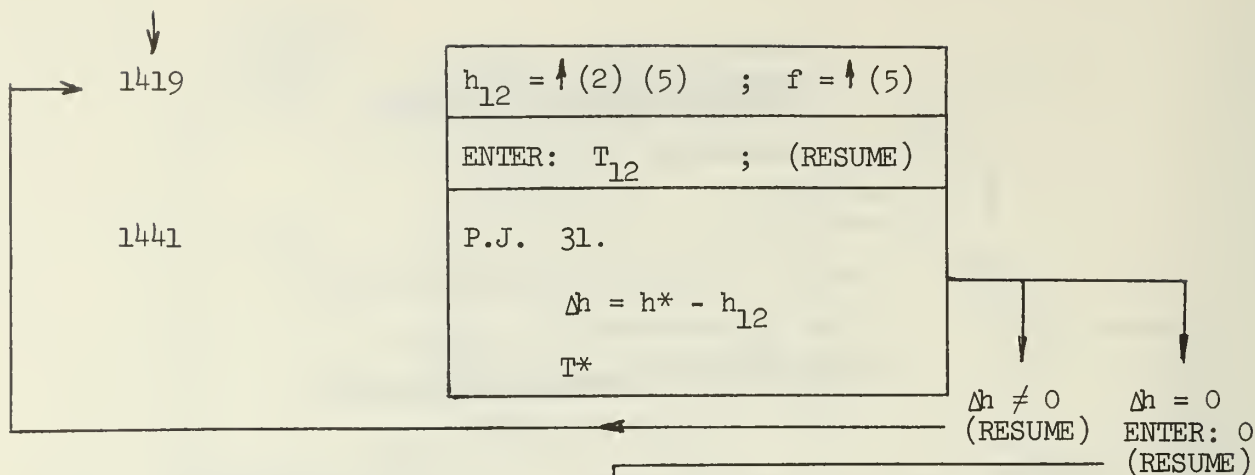
P.I. 30.

$$\Delta\varphi = \varphi^* - \varphi_{12}'$$

T^*

$\Delta\varphi \neq 0$
 (RESUME)

$\Delta\varphi = 0$
 ENTER: 0
 (RESUME)



Print-Out A(P.I. -1,112.)
Exhaust Nozzle Data

Print-Out (P.I. -200.):

I_{SP} = Specific Impulse (lbf/(lbm/s))

SFC = Specific Fuel Consumption $\left(\frac{\text{lb fuel/hr}}{\text{lb thrust}} \right)$

b = Bypass Ratio

M_d = Mach Number of Flow at Exit of Jet Nozzle

P-COUNT

Data of first-stage rotor of low compressor:

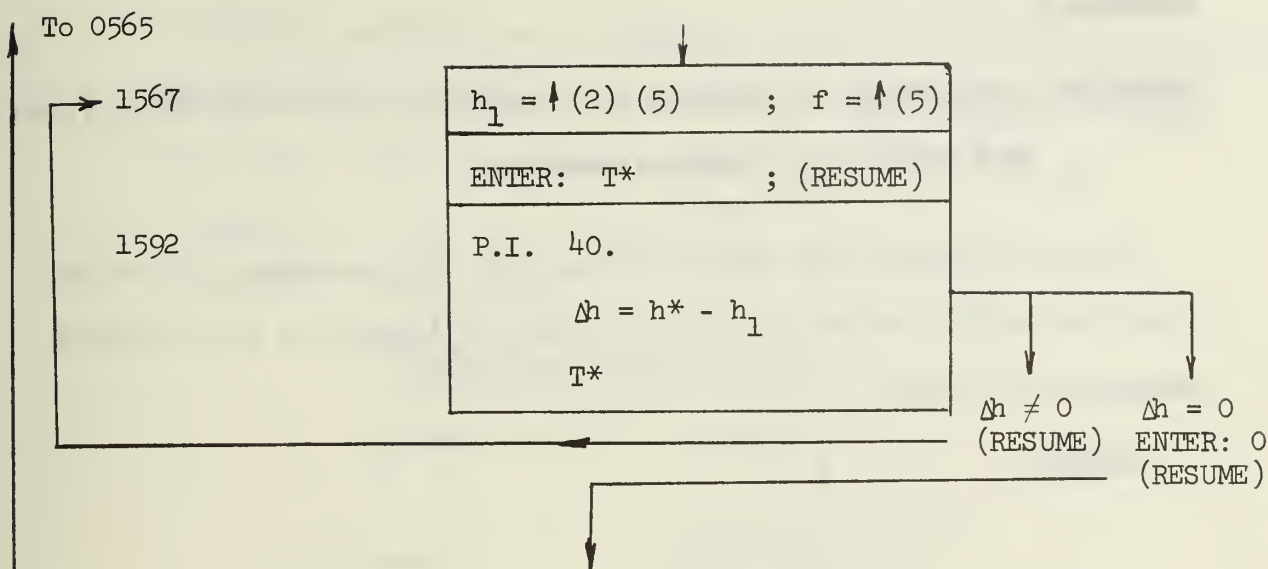
0565 ENTER: D_{T1} = tip diameter (inches)

0579 " : r_{h1} = hub/tip ratio

0587 " : K_1 = blockage factor

0595 " : β_{1T} = relative flow angle at tip ($^\circ$)

0608 " : U_T = peripheral speed at tip (ft/s)



Print-Out A(P.I. -701.)

Inlet Duct Data

Print-Out Engine Data (P.I. -300.)

D_{T1}

r_{h1}

U_T

β_{1T}

K_1

see Input above

F = thrust (lbf)

$\dot{w}$ = total air flow rate (lbm/s)

HP_{LC} = horse power low compressor (HP)

HP_{HC} = horse power high compressor (HP)

M_{w1} = Mach number of relative flow at
tip of first stage of low compressor

Program stops at P-Count 0565 for processing of other sets of data of first-stage rotor of low compressor.

APPENDIX B

OPERATING INSTRUCTIONS OF PROGRAMS VA 513 AND VA 514 FOR JET ENGINE WITHOUT DUCT BURNER AND WITHOUT AFTERBURNER.

In the following only the deviations from the procedure of Appendix A are indicated. In step a) ("Enter Data") of Appendix A the following changes must be made:

P-Count

.
.
.
0231 $T_9 = T_{10} = 0$
.
.
.
.
0251 λ_{AB} (can be zero or not, depending on whether the duct-
and afterburner is installed, although not operating)
.
.
.
.
.
0275 $\eta_{AB} = 1.0$ (this value must be 1.0)
.
.
.

The same procedure as in Appendix A must be carried out until P-Count 0332 is reached; that is, until the bypass ratio b has been printed (P.I. -700). Then, the following steps must be carried out:

P-Count

0332 P.I. -700.

Print-Out of Bypass Ratio b

If b is ok

If b is not ok,
start with new
data at Step a)
of Appendix A

↑ () ()

8

0

Enter on
keyboard

↓ () ()

4

5

(RESUME)

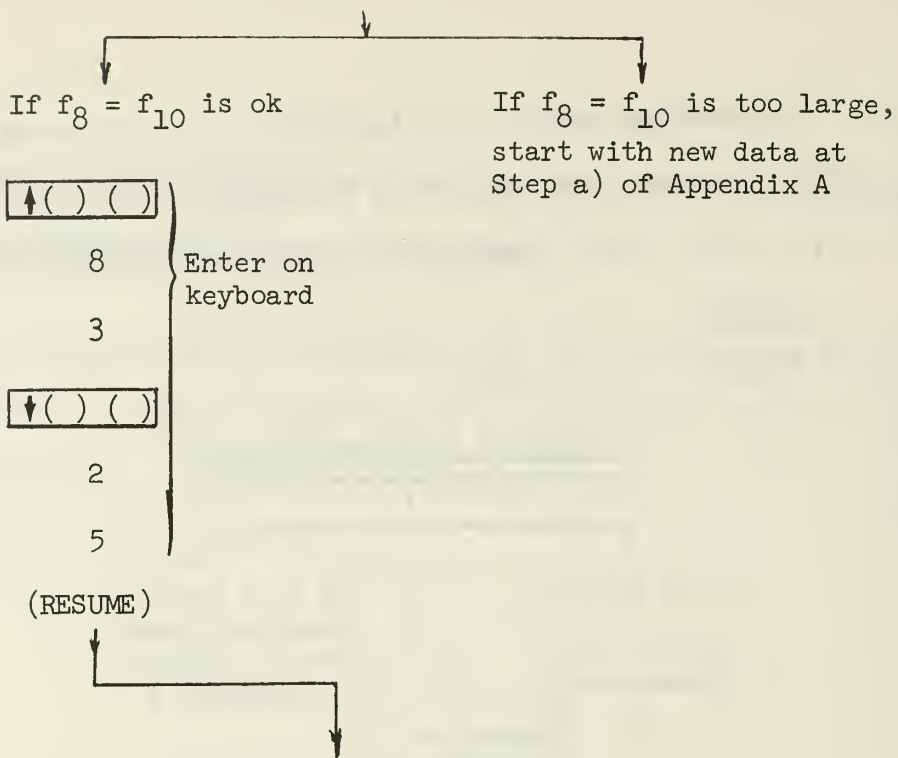
Print-Out B(P.I. -710.)

Conditions at Station 10
of Fig. 1 (Identical with
those at Station 8)

0376

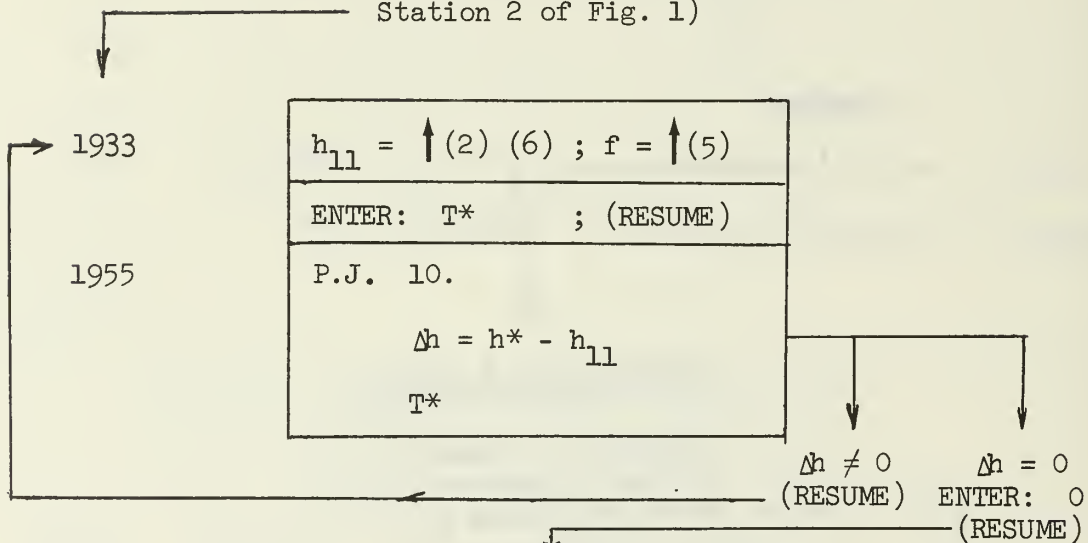
Check of maximum fuel/air ratio

$f_{10} = f_8$ at stations 8 and 10 (last
value of above print-out P.I. -710.)



Conditions after Duct Burner

(Identical with those at Station 2 of Fig. 1)



Print-out C(P.I. -711)

Conditions at Station 11
Mixed Bypass and Engine Flow

(Continue with procedure of Appendix A at P-Count 1361)

(Iteration of T_{12}' for ϕ_{12}')

APPENDIX C. LISTING OF PROGRAMS

Program VA 513 (7 pages)

Program VA 514 (40 pages)

Contents Scratch Pad Registers (1 page)

Contents Main Data Registers (3 pages)

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
0	0	.				
1		2				
2		4				
3		0				
4		6				
5		2	C ₁			
6		↓() ()				
7		0				
8		1			C ₁ → 01	
9		.	←			
1	0	1				
1		7				
2		7				
3		2				
4		4				
5		EXP				
6		CHSGN				
7		4	C ₂			
8		↓() ()				
9		0				
2	0	2	←		C ₂ → 02	
1		.				
2		3				
3		8				
4		0				
5		5				
6		6				
7		EXP				
8		CHSGN				
9		7	C ₃			
3	0	↓() ()				
1		0				
2		3			C ₃ → 03	
3		.	←			
4		1				
5		2				
6		6				
7		6				
8		2				
9		EXP				
4	0	CHSGN				
1		1				
2		0	C ₄			
3		↓() ()				
4		0				
5		4			C ₄ → 04	
6		.	←			
7		1				
8		3				
9		0				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
5	0	1				
	1	2				
	2	EXP				
	3	CHSGN				
	4	1				
	5	4	C ₅			
	6	↓() ()				
	7	0				
	8	5			C ₅ → 05	
6	0	2				
	1	2				
	2	0				
	3	9				
	4	1	D ₁			
	5	↓() ()				
	6	1				
	7	1			D ₁ → 11	
	8	.				
7	0	1				
	1	8				
	2	2				
	3	2	1			
	4	EXP				
	5	CHSGN				
	6	3	D ₂			
	7	↓() ()				
	8	1				
8	0	.			D ₂ → 12	
	1	1				
	2	9				
	3	4				
	4	6				
	5	2				
	6	EXP				
	7	CHSGN				
	8	6	D ₃			
9	0	↓() ()				
	1	1				
	2	3			D ₃ → 13	
	3	.				
	4	4				
	5	5				
	6	0				
	7	8				
	8	9				
	0	EXP				
	1	CHSGN				
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
10	0	1				
1		0	D ₄			
2		↓() ()				
3		1				
4		4	←		D ₄ → 14	
5		.				
6		4				
7		3				
8		2				
9		7				
11	0	5				
1		EXP				
2		CHSGN				
3		1				
4		4				
5		↓() ()				
6		1				
7		5	←		D ₅ → 15	
8		5				
9		.				
12	0	0				
1		3				
2		5				
3		2				
4		3				
5		3				
6		EXP				
7		CHSGN				
8		1	J/R = 778.16/1545.43			
9		↓() ()				
13	0	0				
1		0	←		J/R → 00	
2		3				
3		.				
4		4				
5		5				
6		2				
7		2				
8		EXP				
9		CHSGN				
14	0	2	a = .034522			
1		↓() ()				
2		0				
3		6			a → 06	
4		3				
5		.				
6		5				
7		6				
8		4				
9		8				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
15	0	EXP				
	1	CHSGN				
	2	2	$b = .035648$			
	3	$\downarrow () ()$				
	4	0				
	5	7	$\leftarrow$		$b \rightarrow 07$	
	6	1				
	7	.				
	8	8				
	9	4				
16	0	EXP				
	1	4	$LHV = 18400$			
	2	$\downarrow () ()$				
	3	0				
	4	8	$\leftarrow$		$LHV \rightarrow 08$	
	5	2				
	6	6				
	7	0	$h_f = 260$			
	8	$\downarrow () ()$				
	9	0				
17	0	9	$\leftarrow$		$h_f \rightarrow 09$	
	1	7				
	2	7				
	3	8				
	4	.				
	5	1				
	6	6	J			
	7	$\downarrow () ()$				
	8	1				
	9	0	$\leftarrow$		$J \rightarrow 10$	
18	0	x				
	1	2				
	2	x	$2J$			
	3	3				
	4	2				
	5	.				
	6	1				
	7	7				
	8	4	q		q	
	9	$\downarrow () ()$				
19	0	1				
	1	6			$q \rightarrow 16$	
	2	=	$2qJ$			
	3	$\downarrow () ()$				
	4	1				
	5	8			$2qJ \rightarrow 18$	
	6	$\uparrow () ()$				
	7	1				
	8	0	J			
	9	$\div$				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
200		5				
1		5				
2		0				
3		=	J/550			
4		↓()()				
5		1				
6		7			J/550 → 17	
7		SET D.P				
8		4				
9	EC	377	NO OP			
210		HALT	P ₀ (P ₀ ia)	P ₀		
1		↓()()				
2		4				
3		0			P ₀ → 40	
4		HALT	T ₀ (°R)	T ₀		
5		↓()()				
6		4				
7		1			T ₀ → 41	
8		HALT	P ₂ /P ₁	P ₂ /P ₁		
9		↓()()				
220		4				
1		2			P ₂ /P ₁ → 42	
2		HALT	P ₃ /P ₁	P ₃ /P ₁		
3		↓()()				
4		4				
5		3			P ₃ /P ₁ → 43	
6		HALT	T ₄ (°R)	T ₄		
7		↓()()				
8		4				
9		4			T ₄ → 44	
230		HALT	T ₉ = T ₁₀ (°R)	T ₉ = T ₁₀		
1		↓()()				
2		4				
3		5			T ₉ = T ₁₀ → 45	
4		HALT	ξ	ξ		
5		↓()()				
6		4				
7		6			ξ → 46	
8		HALT	λ _I	λ _I		
9		↓()()				
240		4				
1		7			λ _I → 47	
2		HALT	λ _{BP}	λ _{BP}		
3		↓()()				
4		4				
5		8			λ _{BP} → 48	
6		HALT	λ _B	λ _B		
7		↓()()				
8		4				
9		9			λ _B → 49	

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
25	0	HALT	$\gamma_{DB} = \gamma_{AB}$	$\gamma_{DB} = \gamma_{AB}$		
	1	$\downarrow () ()$				
	2	5				
	3	0			$\gamma_{AB} \rightarrow 50$	
	4	HALT	γ_{LC}	γ_{LC}		
	5	$\downarrow () ()$				
	6	5				
	7	1			$\gamma_{LC} \rightarrow 51$	
	8	HALT	γ_{HC}	γ_{HC}		
	9	$\downarrow () ()$				
26	0	5				
	1	2			$\gamma_{HC} \rightarrow 52$	
	2	HALT	γ_{HT}	γ_{HT}		
	3	$\downarrow () ()$				
	4	5				
	5	3			$\gamma_{HT} \rightarrow 53$	
	6	HALT	γ_{LT}	γ_{LT}		
	7	$\downarrow () ()$				
	8	5				
	9	4			$\gamma_{LT} \rightarrow 54$	
27	0	HALT	γ_B	γ_B		
	1	$\downarrow () ()$				
	2	5				
	3	5			$\gamma_B \rightarrow 55$	
	4	HALT	γ_{AB}	γ_{AB}		
	5	$\downarrow () ()$				
	6	5				
	7	6			$\gamma_{AB} \rightarrow 56$	
	8	HALT	ψ_N	ψ_N		
	9	$\downarrow () ()$				
28	0	5				
	1	7			$\psi_N \rightarrow 57$	
	2	EC 176	1 LINE OF DOTS			
	3	ADVANCE				
	4	4				
	5	1	POINTER 41			
	6	$\downarrow () ()$				
	7	5				
	8	9	STORE PT. 41 in 59			
	9	$\downarrow ()$				
29	0	.	SET UP PT 41			
	1	$\uparrow () ()$				
	2	4				
	3	0	P_0			
	4	1	$\uparrow$			
	5	0	PRINT IDENTIFIER -100.			
	6	0				
	7	.				
	8	CHSGN	$\downarrow$			
	9	EC 177				100.

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
3 0 0		PRINT A				P ₀
1	✓	IND/SYMB	↑ SYMBOL. ADDRESS ✓			
2		✓	↓			
3		↑() ()	↑ RCL & PRINT ACCORDING TO			
4		IND/SYMB	↓ POINTER			
5		PRINT A				
6		1	1 ↑			
7		↑() ()	ADD 1 TO POINTER STR(E)			
8		+				
9		5				
3 1 0		9				
1		↓() ()				
2		5				
3		9	STR NEW POINTER IN REG. 59		PT → 59	
4		↓()				
5		.	SET UP NEW POINTER			
6		-				
7		5				
8		8				
9		=	NEW POINTER - 59			
3 2 0		JUMP				
1		=				
2		IND/SYMB				
3		÷				
4		JUMP				
5		IND/SYMB				
6		✓				
7	÷	IND/SYMB				
8		÷				
9		SET D.P.				
3 3 0		6	SET D.P. TO 6 FOR VA 514			
1	EC	176	1 LINE OF DOTS			....
2		HALT	CHECK OF INPUT DATA			
3						
4						
5						
6						
7						
8						
9						
3 4 0						
1						
2						
3						
4						
5						
6						
7						
8						
9						

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
000	0	↑() ()				
1		4				
2		1	T_0			
3		↓() ()				
4		2				
5		1			$T_0 \rightarrow 21$	
6		↑() ()				
7		4				
8		2	P_2/P_1			
9		↓() ()				
010	0	2				
1		0			$P_2/P_1 \rightarrow 20$	
2		↑() ()				
3		5				
4		1	η_{LC}			
5		↓() ()				
6		2				
7		3	-		$\eta_{LC} \rightarrow 23$	
8		1	↑			
9		2				
020	0	.				
1		CHSGN	PRINT IDENTIF. - 12 FOR LC			
2		↓() ()	STR (36)			
3		3				
4		6	↓		$PI \rightarrow 36$	
5	EC	016	SET FLAG 1			
6	EC	377	NO OP.			
7		JUMP	GO TO SUBROUTINE ÷ COMPRESSOR (LC)			
8		IND/SYM				- 12
9		÷				LC DATA
030	EC 040	IND/SYM	SYMB. ADDRESS EC 040			
1	EC	040				
2	EC	166	RESET FLAG 1			
3		↑() ()				
4		2				
5		6	$h_2 - h_1$			
6		↓() ()				
7		7				
8		0			$h_2 - h_1 \rightarrow 70$	
9		↑() ()				
040	0	2				
1		4	T_2			
2		↓() ()				
3		8				
4		3			$T_2 \rightarrow 83$	
5		↓() ()				
6		2				
7		1			$T_2 \rightarrow 21$	
8		↑() ()				
9		4				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
050		3	P_3/P_1			
1		$\div$				
2		$\uparrow () ()$				
3		4				
4		2	P_2/P_1			
5		=	P_3/P_2			
6		$\downarrow () ()$				
7		2				
8		0			$P_3/P_2 \rightarrow 20$	
9		$\uparrow () ()$				
060		5				
1		2	η_{HC}			
2		$\downarrow () ()$				
3		2				
4		3			$\eta_{HC} \rightarrow 23$	
5		2				
6		3	PRINT IDENTIF. -23. FOR HC			
7		.	STR (36)			
8		CHSGN				
9		$\downarrow () ()$				
070		3				
1		6			$PI \rightarrow 36$	
2		JUMP	$\uparrow$ GO TO SUBROUTINE $\div$ "COMPRESSOR" (HC)			
3		IND/SYM				-23
4		$\div$				HC DATA
5	EC 041	IND/SYMB				
6	EC	041				
7		$\uparrow () ()$				
8		2				
9		6	h_3-h_2			
080		$\downarrow () ()$				
1		7				
2		1			$h_3-h_2 \rightarrow 71$	
3		$\uparrow () ()$				
4		2				
5		4	T_3			
6		$\downarrow () ()$				
7		7				
8		2			$T_3 \rightarrow 72$	
9		$\downarrow () ()$				
090		2				
1		0			$T_3 = T_i \rightarrow 20$	
2		0	0			
3		$\downarrow () ()$				
4		2			$f_i = 0 \rightarrow 21$	
5		1	$f_i = 0$			
6		$\uparrow () ()$				
7		4				
8		4	$T_4 = T_e$			
9		$\downarrow () ()$				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 0 0		2				
	1	5			$T_A = T_c \rightarrow 25$	
	2	$\uparrow()()$				
	3	5				
	4	5	η_B			
	5	$\downarrow()()$				
	6	2			$\eta_B \rightarrow 22$	
	7	2				
	8	7	$\uparrow$			
	9	0				
1 1 0		4	PRINT IDENTIF. -704 FOR			
	1	CHSGN	MAIN BURNER EXIT			
	2	$\downarrow()()$				
	3	2				
	4	9			$PI \rightarrow 29$	
	5	BRANCH	$\uparrow$ CALL SUBROUTINE "BURNER"			
	6	IND/SYMB	FOR MAIN COMBUSTOR			-704
	7	a^*	$\downarrow$			PRINT
	8	$\uparrow()()$				
	9	2				
1 2 0		7	$\Delta f = f_B'$			
	1	$\downarrow()()$				
	2	7				
	3	3			$f_B' \rightarrow 73$	
	4	$\downarrow()()$				
	5	2				
	6	7			$f_B' \rightarrow 27$	
	7	+				
	8	1				
	9	x	$1 + f_B'$			
1 3 0		(				
	1	1				
	2	-				
	3	$\uparrow()()$				
	4	4				
	5	6	ξ			
	6	)	$1 - \xi$			
	7	=	$(1 + f_B')(1 - \xi)$			
	8	INV				
	9	x				
1 4 0		$\uparrow()()$				
	1	7				
	2	1	$h_3 - h_2$			
	3	=	$\Delta h = h_4 - h_5$			
	4	$\downarrow()()$				
	5	2				
	6	6			$h_4 - h_5 \rightarrow 26$	
	7	$\uparrow()()$				
	8	5				
	9	3	η_{HT}			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
150		↓() ()				
1		2				
2		3			$\eta_{HT} \rightarrow 23$	
3		4	↑			
4		5	PRINT IDENTIF. -45 FOR HT			
5		CHSGN	STR(36)			
6		↓() ()				
7		3				
8		6	↓		$PJ \rightarrow 36$	
9		↑() ()				
160		4				
1		4	T_4			
2		↓() ()				
3		2				
4		1			$T_4 \rightarrow 21$	
5	EC	016	SET FLAG 1			
6		JUMP	↑			
7		IND/SYMB	GO TO SUBROUTINE HT			-45
8		π/e	↓			DATA
9	EC 042	IND/SYMB	SYMB. ADDRESS EC 042			
170		EC 042				
1	EC	166	RESET FLAG 1			
2		↑() ()				
3		2				
4		0	P_5/P_4			
5		↓() ()				
6		7				
7		4			$P_5/P_4 \rightarrow 74$	
8		↑() ()				
9		2				
180		4	T_5			
1		↓() ()				
2		7				
3		5			$T_5 \rightarrow 75$	
4		↓() ()				
5		2				
6		0			$T_5 = T_i \rightarrow 20$	
7		↑() ()				
8		7				
9		3	f_B'			
190		↓() ()				
1		2				
2		1			$f_i = f_B' \rightarrow 21$	
3		↑() ()				
4		7				
5		2	T_3			
6		↓() ()				
7		2				
8		2			$T_3 = T_{ii} \rightarrow 22$	
9		0	0			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
2 0	0	↓() ()				
	1	2				
	2	3			$f_{ii}=0 \rightarrow 23$	
	3	↑() ()				
	4	4				
	5	6	ξ			
	6	÷				
	7	(				
	8	1				
	9	-				
2 1	0	↑() ()				
	1	4				
	2	6	ξ			
	3	)	$1-\xi$			
	4	=	$\xi = \xi / (1-\xi)$			
	5	↓() ()				
	6	2				
	7	7			$\xi \rightarrow 27$	
	8	7	↑			
	9	0				
2 2	0	6	PRINT IDENTIF. - 706			
	1	CHSGN	FOR STATION 6			
	2	↓() ()	STR(29)			
	3	2				
	4	9	↓		$PI \rightarrow 29$	
	5	EC 016	SET FLAG 1			
	6	JUMP	↑ GO TO SUBROUTINE "MIXING" FOR			
	7	IND/SYMB	STATION 6 AFTER HT			
	8	Φ	↓			
	9	EC 043 IND/SYMB	↑ SYMBOL. ADDRESS EC 043			
2 3	0	EC 043	↓			
	1	EC 166	RESET FLAG 1			
	2	↑() ()				
	3	2				
	4	5	T_6			
	5	↓() ()				
	6	2				
	7	1			$T_6 = T_i \rightarrow 21$	
	8	↑() ()				
	9	2				
2 4	0	8	$f_B = f_e$			
	1	↓() ()				
	2	2			$f_B = f_e \rightarrow 27$	
	3	7				
	4	↑() ()				
	5	5				
	6	4	η_{LT}			
	7	↓() ()				
	8	2				
	9	3			$\eta_e = \eta_{LT} \rightarrow 23$	

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
2 5 0		1	1			
1		-				
2		f() ()				
3		4				
4		8	λ_{BP}			
5		$\div$	$1 - \lambda_{BP}$			
6		(				
7		1	1			
8		-				
9		f() ()				
2 6 0		4				
1		9	λ_B			
2		)	$1 - \lambda_B$			
3		x				
4		f() ()				
5		4				
6		2	P_2/P_1			
7		$\div$				
8		f() ()				
9		4				
2 7 0		3	P_3/P_1			
1		$\div$				
2		f() ()				
3		7				
4		4	P_5/P_4			
5		=	P_8/P_5			
6		d() ()				
7		7				
8		6				$P_8/P_5 \rightarrow 76$
9		d() ()				
2 8 0		2				
1		0				$P_8/P_5 \rightarrow 20$
2		6	$\uparrow$			
3		8	PRINT IDENTIF. - 68 FOR LT			
4		CHSGN				
5		d() ()				
6		3				
7		6	$\downarrow$			$PJ \rightarrow 36$
8	EC	0 16	SET FLAG 1			
9		JUMP	GO TO SUBROUTINE "EXPANS."			
2 9 0		IND/SYMB	FOR LT			-68 PRINT
1		x				
2	EC 044	IND/SYMB	SYMBOL. ADDRESS EC 044			
3	EC	0 44				
4	EC	1 6 6	RESET FLAG 1			
5		f() ()				
6		2				
7		6	$h_6 - h_8$			
8		d() ()				
9		7				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
300		8				
1		x				
2		(				
3		1	1			
4		+				
5		↑()()				
6		2				
7		7	f_B			
8		↓()()				
9		7				
310		7			$f_B \rightarrow 77$	
1		↓()()				
2		2				
3		1			$f_B \rightarrow 21$	
4		)	$1 + f_B$			
5		÷				
6		↑()()				
7		7				
8		0	$h_2 - h_1$			
9		-				
320		1				
1		=	b			
2		↓()()				
3		7				
4		9			$b \rightarrow 79$	
5		7	↑			
6		0				
7		0	P.I. - 700.			
8		CHSGN	↓			
9	EC	177				-700.
330		PRINTA				b
1		HALT	Check b: Without AB: ↑(8)(0) ↓(4)(5)			
2		↑()()				
3		2				
4		4	T_B			
5		↓()()				
6		8				
7		0			$T_B \rightarrow 80$	
8		↓()()				
9		2				
340		0			$T_B = T_i \rightarrow 20$	
1		↑()()				
2		5				
3		6	η_{AB}			
4		↓()()				
5		2				
6		2			$\eta_{AB} \rightarrow 22$	
7		↑()()				
8		4				
9		5	T_9			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
350		↓() ()				
1		2				
2		5			$T_e T_9 \rightarrow 25$	
3		7	↑			
4		1	P.I. - 710.			
5		0	CONDITIONS STATION 10			
6		CHSGN	AFTER A.B.			
7		↓() ()				
8		2				
9		9	↓		P.I. → 29	
360		BRANCH	↑ CALL S.R. "BURNER", a^x			
1		IND/SYMB	FOR AB.			-710 DATA
2		a^x	↓			
3		↑() ()				
4		2				
5		7	Δf_{AB}			
6		↓() ()				
7		8				
8		1			$\Delta f_{AB} \rightarrow 81$	
9		↑() ()				
370		2				
1		8	f_e			
2		↓() ()				
3		8				
4		2			$f_e \rightarrow 82$	
5		HALT	CHECK f_{max} ? With out AB: ↑(8)(3) ↓(2)(5)			
6		↑() ()				
7		8				
8		3	$T_2 = T_i$			
9		↓() ()				
380		2				
1		0			$T_2 = T_i \rightarrow 20$	
2		0	$f_i = 0$			
3		↓() ()				
4		2				
5		1			$0 = f_i \rightarrow 21$	
6		7	↑			
7		0	P.I. - 709			
8		9	CONDITIONS STATION 9			
9		CHSGN	AFTER DUCT BURNER			
390		↓() ()				
1		2				
2		9	↓		P.I. → 29	
3		BRANCH	↑ CALL S.R. "BURNER", a^x			
4		IND/SYMB	FOR D.B.			-709 DATA
5		a^x	↓			
6		↑() ()				
7		2				
8		8	f_{DB}			
9		↓() ()				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
4 0 0		2		$f_{DB} = f_{ii} \rightarrow 23$		
1		3				
2		$\uparrow()()$				
3		8				
4		2	$f_B + f_{AB}$			
5		$\downarrow()()$				
6		2		$f_B + f_{AB} = f_i \rightarrow 21$		
7		1				
8		$\uparrow()()$				
9		4				
4 1 0		5	$T_9 = T_{10}$			
1		$\downarrow()()$				
2		2		$T_9 = T_i \rightarrow 20$		
3		0	$T_i = T_9$			
4		$\uparrow()()$				
5		2				
6		5	T_e from S.R. D.B = T_{ii}			
7		$\downarrow()()$				
8		2				
9		2		$T_{ii} \rightarrow 22$		
4 2 0		7	$\uparrow$			
1		1	P.I. - 711			
2		1	CONDITIONS STATION II			
3		CHSGN	MIXED AB & DB FLOWS			
4		$\downarrow()()$				
5		2				
6		9	$\downarrow$	$P.I \rightarrow 29$		
7		$\uparrow()()$				
8		7				
9		9	$b = \zeta$			
4 3 0		$\downarrow()()$				
1		2				
2		7		$b = \zeta \rightarrow 27$		
3		JUMP	$\uparrow$ TO S.R. "MIXING", Φ			
4		IND/SYMB	$\downarrow$ MIXING OF AB & DB FLOWS			-711
5		Φ				DATA
6	EC 045	IND/SYMB	$\uparrow$ SYMB. ADDRESS EC 045			
7	EC	045	$\downarrow$			
8		$\uparrow()()$				
9		2				
4 4 0		8	$f_e = f_N$			
1		$\downarrow()()$				
2		8				
3		4		$f_N \rightarrow 84$		
4		$\downarrow()()$				
5		2				
6		7		$f = f_N \rightarrow 27$		
7		$\uparrow()()$				
8		5				
9		7	ψ_N			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
450		X				
1		=	$\psi_N^2 = \gamma_N$			
2		↓() ()				
3		2				
4		3			$\gamma_N \rightarrow 23$	
5		↑() ()				
6		2				
7		5	$T_9 = T_i$			
8		↓() ()				
9		2			$T_9 = T_i \rightarrow 21$	
460		1				
1		1	1			
2		-				
3		↑() ()				
4		4				
5		7	λ_I			
6		X				
7		(				
8		1	1			
9		-				
470		↑() ()				
1		4				
2		8	λ_{BP}			
3		)	$1 - \lambda_{BP}$			
4		X				
5		(				
6		1	1			
7		-				
8		↑() ()				
9		5				
480		0	λ_{AB}			
1		)	$1 - \lambda_{AB}$			
2		X				
3		↑() ()				
4		4				
5		2	P_2/P_1			
6		=	P_{11}/P_{12}			
7		1/X	P_{12}/P_{11}			
8		↓() ()				
9		2				
490		0			$P_{12}/P_{11} \rightarrow 20$	
1		1				
2		1	P.I. - 1112			
3		1	FOR EXHAUST NOZZLE			
4		2				
5		CHSGN				
6		↓() ()				
7		3				
8		6			$IP \rightarrow 36$	
9		JUMP				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
50	0	IND/SYMB	TO S.R. "EXPANSION", X			-1112
	1	X	FOR JET NOZZLE			DATA
	2	EC 046	SYMB. ADDRESS EC 046			
	3	EC 046				
	4	$\uparrow()()$				
	5	3				
	6	4	V_d			
	7	X				
	8	(				
	9	1	1			
51	0	+				
	1	$\uparrow()()$				
	2	8				
	3	4	f_N			
	4	)	$1 + f_N$			
	5	$\div$				
	6	$\uparrow()()$				
	7	1				
	8	6	g			
	9	=	I_{SP}			
52	0	$\downarrow()()$				
	1	8				
	2	5			$I_{SP} \rightarrow 85$	
	3	$\downarrow()()$				
	4	2				
	5	5			$I_{SP} \rightarrow 25$	
	6	$1/X$	$1/I_{SP}$			
	7	X				
	8	$\uparrow()()$				
	9	8				
53	0	4	f_N			
	1	X				
	2	3				
	3	6				
	4	0				
	5	0	3600			
	6	=	SFC			
	7	$\downarrow()()$				
	8	2				
	9	6			$SFC \rightarrow 26$	
54	0	$\uparrow()()$				
	1	7				
	2	9	b			
	3	$\downarrow()()$				
	4	2				
	5	7			$b \rightarrow 27$	
	6	$\uparrow()()$				
	7	3				
	8	5	M_d			
	9	$\downarrow()()$				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
550		2				
1		8			$M_d \rightarrow 28$	
2		2	$\uparrow$			
3		0	P.I. - 200			
4		0	FOR OVERALL PERFORMANCE			
5		CHSGN				
6		$\downarrow()()$				
7		2				
8		9	$\downarrow$		$P.I. \rightarrow 29$	
9		BRANCH	$\uparrow$			
560		IND/SYMB	CALL S.R. "PRINT II", $\uparrow()$			-200
1		$\uparrow()$	$\downarrow$ FOR OVERALL PERFORMANCE			DATA
2	EC 060	IND/SYMB	$\uparrow$ SYMB. ADDRESS EC 060			
3	EC	060	$\downarrow$			
4		HALT	D_{T1}	D_{T1}		
5		$\downarrow()()$				
6		6				
7		0			$D_{T1} \rightarrow 60$	
8		X				
9		X				
570		π				
1		$\div$				
2		4				
3		X				
4		(				
5		1	1			
6		-				
7		(				
8		HALT	r_{h1}	r_{h1}		
9		$\downarrow()()$				
580		6				
1		1			$r_{h1} \rightarrow 61$	
2		X				
3		)	r_{h1}^2			
4		)	$1 - r_{h1}^2$			
5		X				
6		HALT	k_i	k_i		
7		$\downarrow()()$				
8		6				
9		4			$k_i \rightarrow 64$	
590		=	$C = \frac{\pi}{4} D_{T1}^2 (1 - r_{h1}^2)$			
1		$\downarrow()()$				
2		9				
3		2			$C \rightarrow 92$	
4		HALT	β_{IT}	β_{IT}		
5		$\downarrow()()$				
6		6				
7		3			$\beta_{IT} \rightarrow 63$	
8		SIN/COS	$\sin \beta_{IT}$			
9		$\downarrow()()$				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
600		9				
1		0			$\sin \beta_{IT} \rightarrow 90$	
2		$\div$				
3		2NDFUNC	$\cos \beta_{IT}$			
4		=	$\tan \beta_{IT}$			
5		$1/x$	$\cot \beta_{IT}$			
6		X				
7		HALT	U_T	U_T		
8		$\downarrow()()$				
9		6				
610		2				
1		X	$U_T \cot \beta_{IT}$		$U_T \rightarrow 62$	
2		$\downarrow()()$				
3		9				
4		1			$U_T \cot \beta_{IT} \rightarrow 91$	
5		$\div$	$(U_T \cot \beta_{IT})^2$			
6		$\uparrow()()$				
7		1				
8		8	$2gJ$			
9		=	$h_1 - h_{s1} = \Delta h$			
620		$\downarrow()()$				
1		2				
2		6			$\Delta h \rightarrow 26$	
3		$\uparrow()()$				
4		4				
5		1	$T_0 = T_1$			
6		$\downarrow()()$				
7		2				
8		1			$T_1 \rightarrow T_2 \rightarrow 21$	
9		1	$\eta = 1$			
630		$\downarrow()()$				
1		2				
2		3			$\eta = 1 \rightarrow 23$	
3		0	$0 = f$			
4		$\downarrow()()$				
5		2			$0 = f \rightarrow 27$	
6		7				
7		1	$\uparrow$ P.I. -101			
8		0	INLET DUCT			
9		1				
640		CHSGN				
1		$\downarrow()()$				
2		3				
3		6				
4		JUMP	$\uparrow$ TO S.R. "EXPANSION", π/e			
5		IND/SYMB	FOR INLET DUCT			-101
6		π/e	$\downarrow$			DATA
7	EC 047	IND/SYMB	$\uparrow$ SYMB. ADDRESS EC 047			
8	EC	047	$\downarrow$			
9		$\uparrow()()$	71			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
65	0	2				
	1	0	$P_{s1}/P_i = P_e/P_i$			
	2	X				
	3	(				
	4	1	1			
	5	-				
	6	↑()()				
	7	4				
	8	7	λ_z			
	9	)	$1 - \lambda_z$			
66	0	X				
	1	↑()()				
	2	4				
	3	0	P_0			
	4	÷				
	5	↑()()				
	6	2				
	7	9	R_G			
	8	÷				
	9	↑()()				
67	0	2				
	1	4	T_{s1}			
	2	X				
	3	↑()()				
	4	9				
	5	1	$U_T \cot \beta_{1T}$			
	6	X				
	7	↑()()				
	8	9				
	9	2	C			
68	0	X	$\dot{w}$			
	1	↓()()				
	2	6				
	3	6			$\dot{w} \rightarrow 66$	
	4	↑()()				
	5	8				
	6	5	I_{sp}			
	7	=	F			
	8	$\frac{1}{2}$	↑ delete fractions of F			
	9	5	↑			
69	0	↓()()				
	1	6				
	2	5			$F \rightarrow 65$	
	3	↑()()				
	4	6				
	5	2	U_T			
	6	÷				
	7	↑()()				
	8	9				
	9	0	$\sin \beta_{1T}$			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
700		$\div$	$W_1 = U_T / \sin \beta_{1T}$			
1		$\uparrow () ()$				
2		3				
3		5	a_{s1}			
4		=	M_{W1}			
5		$\downarrow () ()$				
6		6				
7		9			$M_{W1} \rightarrow 69$	
8		$\uparrow () ()$				
9		6				
710		6	$\dot{w}$			
1		x				
2		$\uparrow () ()$				
3		1				
4		7	$J/550$			
5		x	$\dot{w} J/550$			
6		$\uparrow () ()$				
7		7				
8		0	$h_2 - h_1$			
9		=	HP_{LC}			
720		Φ	$\uparrow$			
1		5	delete fractions of HP_{LC}			
2		$\downarrow () ()$				
3		6				
4		7			$HP_{LC} \rightarrow 67$	
5		$\uparrow () ()$				
6		7				
7		1	$h_3 - h_2$			
8		=	$(\dot{w} J/550)(h_3 - h_2)$			
9		$\div$				
730		(				
1		1	1			
2		+				
3		$\uparrow () ()$				
4		7				
5		9	b			
6		)	$1 + b$			
7		=	HP_{HC}			
8		Φ	$\uparrow$			
9		5	delete fractions of HP_{HC}			
740		$\downarrow () ()$				
1		6				
2		8			$HP_{HC} \rightarrow 68$	
3		6				
4		1	↑ POINTER 61 STR (59)			
5		$\downarrow () ()$				
6		5				
7		9	↓		$PT \rightarrow 59$	
8		$\downarrow ()$	↑ SET UP POINTER 61			
9		.	↓			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
750		$\uparrow()$				
1		6				
2		0	DT ₁			
3		3	$\uparrow$			
4		0				
5		0	PI. - 300			
6		CHSGN				
7	EC	177	$\downarrow$			-300
8		PRINTA				DT ₁
9	EC 062	IND/SYMB	$\uparrow$ SYMB. ADDRESS EC 062			
760	EC	062	$\downarrow$			
1		$\uparrow()$	$\uparrow$ RCL ACCORD. TO POINTER			
2		IND/SYMB	$\downarrow$			
3		PRINTA				PRINT
4		1	1			POINTER
5		$\uparrow()$				
6		+				
7		5				
8		9	ADD 1 TO POINTER, STR(E)			
9		$\downarrow()$				
770		5				
1		9	STR POINTER IN 59		POINT. $\rightarrow$ 59	
2		$\downarrow()$				
3		.	SET UP NEW POINTER			
4		-				
5		7				
6		0	70			
7		=	NEW POINTER - 70			
8		BRANCH	$\uparrow$			
9		=	GO TO S.A. EC 063 IF NEW POINTER			
780		IND/SYMB	$\downarrow$ EQUALS 70			
1	EC	063	$\downarrow$			
2		JUMP	$\uparrow$ GO TO S.A. EC 062 IF NEW POINTER			
3		IND/SYMB	$\downarrow$ ≤ 69			
4	EC	062	$\downarrow$			
5	EC 063	IND/SYMB	$\uparrow$ SYMB. ADDRESS EC 063			
6	EC	063	$\downarrow$			
7	EC	176	$\uparrow$	END		....
8	EC	176	3 LINES OF DOTS	MAIN		....
9	EC	176	$\downarrow$	PROGR		....
790		ADVANCE	$\uparrow$ 2 PAPER ADVANCE			
1		ADVANCE	$\downarrow$			
2		JUMP	$\uparrow$ TO INTRODUCE OTHER FIRST-STAGE			
3		IND/SYMB	LC ROTOR DATA			
4	EC	060	$\downarrow$			
5	-	IND/SYMB	$\uparrow$ SUBROUTINE φ , (-)		T in 0	
6	-	-	$\downarrow$		t in 5	
7		$\uparrow()$				
8		0	T			
9		ln/log	ln T			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
80	0	X				
1		$\uparrow()$				
2		0				
3		1	C_1			
4		-	$C_1 \ln T$			
5		(				
6		$\uparrow()$				
7		0	T			
8		X				
9		$\uparrow()()$				
81	0	0				
1		2	C_2			
2		)	$C_2 T$			
3		+				
4		(				
5		$\uparrow()$				
6		0	T			
7		X				
8		$\div$	T^2			
9		2				
82	0	X	$T^{2/2}$			
1		$\downarrow()$				
2		1			$T^{2/2} \rightarrow 1$	
3		$\uparrow()()$				
4		0				
5		3	C_3			
6		)	$C_3 T^{2/2}$			
7		-				
8		(				
9		$\uparrow()$				
83	0	0	T			
1		a^*				
2		3				
3		$\div$	T^3			
4		3				
5		X	$T^{3/3}$			
6		$\downarrow()$				
7		2			$T^{3/3} \rightarrow 2$	
8		$\uparrow()()$				
9		0				
84	0	4	C_4			
1		)	$C_4 T^{3/3}$			
2		+				
3		(				
4		$\uparrow()$				
5		0	T			
6		a^*				
7		4				
8		$\div$	T^4			
9		4				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
850		X	$T^4/4$			
1		$\downarrow()$				
2		3			$T^4/4 \rightarrow 3$	
3		$\uparrow()()$				
4		0				
5		5	C_5			
6		)	$C_5 T^4/4$			
7		=	φ_A			
8		$\downarrow()$				
9		6			$\varphi_A \rightarrow 6$	
860		$\uparrow()$				
1		0	T			
2		$\ln/\log$	$\ln T$			
3		X				
4		$\uparrow()()$				
5		1				
6		1	D_1			
7		+	$D_1 \ln T$			
8		(				
9		$\uparrow()$				
870		0	T			
1		X				
2		$\uparrow()()$				
3		1				
4		2	D_2			
5		)	$D_2 T$			
6		-				
7		(				
8		$\uparrow()$				
9		1	$T^2/2$			
880		X				
1		$\uparrow()()$				
2		1				
3		3	D_3			
4		)	$D_3 T^{3/2}$			
5		+				
6		(				
7		$\uparrow()$				
8		2	$T^{3/3}$			
9		X				
890		$\uparrow()()$				
1		1				
2		4	D_4			
3		)	$D_4 T^{3/3}$			
4		-				
5		(				
6		$\uparrow()$				
7		3	$T^4/4$			
8		X				
9		$\uparrow()()$				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
900						
1		5	D_5			
2		)	$D_5 T^{4/A}$			
3		x	φ_G			
4		f()				
5		5	f			
6		+	f φ_G			
7		f()				
8		6	φ_A			
9		÷				
910						
1		(				
2		1	1			
3		+				
4		f()				
5		5	f			
6		)	$1+f$			
7		=	$\varphi = [\varphi_A + f \varphi_G] / (1+f)$			
8		↓()				
9		7				
9		RESUME				
920	+	IND/SYMB	SUBROUTINE $h_A, h_G, h(+)$			
1		+				
2		f()				
3		0	T			
4		x				
5		f() ()				
6		0				
7		1	C_1			
8		-	$C_1 T$			
9		(				
930						
1		0	T			
2		x				
3		÷	T^2			
4		2				
5		x	$T^2/2$			
6		↓()				
7		1				
8		f() ()				
9		0				
940						
1		2	C_2			
2		)	$C_2 T^2/2$			
3		+				
4		(				
5		f()				
6		0	T			
7		a^x				
8		÷	T^3			
9		3				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
950		X	$T^{3/3}$			
1		$\downarrow()$				
2		2			$T^{3/3} \rightarrow 2$	
3		$\uparrow()()$				
4		0				
5		3	C_3			
6		)	$C_3 T^{3/3}$			
7		-				
8		(				
9		$\uparrow()$				
960		0	T			
1		a^x				
2		4				
3		$\div$	T^4			
4		4				
5		X	$T^4/4$			
6		$\downarrow()$				
7		3			$T^4/4 \rightarrow 3$	
8		$\uparrow()()$				
9		0				
970		4	C_4			
1		)	$C_4 T^4/4$			
2		+				
3		(				
4		$\uparrow()$				
5		0	T			
6		a^x				
7		5				
8		$\div$	T^5			
9		5				
980		X	$T^5/5$			
1		$\downarrow()$				
2		4			$T^5/5 \rightarrow 4$	
3		$\uparrow()()$				
4		0				
5		5	C_5			
6		)	$C_5 T^5/5$			
7		=	h_A			
8		$\downarrow()$				
9		6			$h_A \rightarrow 6$	
990		$\uparrow()$				
1		0	T			
2		X				
3		$\uparrow()()$				
4		1				
5		1	D_1			
6		+	$D_1 T$			
7		(				
8		$\uparrow()$				
9		1	$T^2/2$			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1000		X				
1		f()				
2		1				
3		2	D_2			
4		)	$D_2 T^{3/2}$			
5		-				
6		(				
7		f()				
8		2	$T^{3/3}$			
9		X				
1010		f()				
1		1				
2		3	D_3			
3		)	$D_3 T^{3/3}$			
4		+				
5		(				
6		f()				
7		3	$T^{4/4}$			
8		X				
9		f()				
1020		1				
1		4	D_4			
2		)	$D_4 T^{4/4}$			
3		-				
4		(				
5		f()				
6		4	$T^{5/5}$			
7		X				
8		f()				
9		1				
1030		5	D_5			
1		)	$D_5 T^{5/5}$			
2		X	h_G			
3		f()				
4		7			$h_G \rightarrow 7$	
5		f()				
6		5	f			
7		+	$f h_G$			
8		f()				
9		6	h_A			
1040		$\div$	$h_A + f h_G$			
1		(				
2		1	1			
3		+				
4		f()				
5		5	f			
6		)	$1 + f$			
7		=	h			
8		f()				
9		8			$h \rightarrow 8$	

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1050		RESUME	J END S.R. h (+)			
1	✓	IND/SYMB	↑ SUBROUTINE "Rg/J" (✓)		f in 5	
2	✓		↓			
3		↑ ()				
4		5	f			
5		x				
6		↑ () ()				
7		0				
8		7	b = .035648			
9		+				
1060		↑ () ()				
1		0				
2		6	a = .034522			
3		÷				
4		(	S.R. Rg/J			
5		1	(✓)			
6		+				
7		↑ ()				
8		5	f			
9		)	1 + f			
1070		÷				
1		↑ () ()				
2		0				
3		0	J/R			
4		=	Rg/J			
5		↓ () ()				
6		2				
7		9			Rg/J → 29	
8		RESUME				
9	↓ ()	IND/SYMB	↑ SUBROUTINE "PRINT I" (↓ ())			
1080		↓ ()	↓			
1		↑ () ()				
2		2				
3		0	Pe/Pi			
4		↑ () ()				
5		3				
6		6	P. I.			
7	EC	177				P. I.
8		PRINTA				Pe/Pi
9		2	↑			
1090		1	SET UP POINTER 21			
1		↓ () ()	STR 37			
2		3				
3		7				
4		↓ ()				
5		.				
6	8	IND/SYMB	↑ SYMBOL. ADDRESS 8			
7		8	↓			
8		↑ () ()	↑ RCL ACCORD. TO POINTER			
9		IND/SYMB	↓			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 1 0	0	PRINT A				PRINT A POINTER
	1	1	1			
	2	f() ()				
	3	+				
	4	3				
	5	7	ADD 1 TO POINTER, STR(E)			
	6	↓() ()				
	7	3				
	8	7	NEW POINTER, STR(37)			
	9	↓()				
1 1 1	0	.	SET UP NEW POINTER			
	1	-				
	2	3				
	3	0	NEW POINTER - 30			
	4	=				
	5	JUMP				
	6	=				
	7	IND/SYMB	↑ TO SYMB. ADD. IF NEW POINTER = 30			
	8	9	↓			
	9	JUMP	↑			
1 1 2	0	IND/SYMB	↑ TO SYMB. ADD IF NEW POINTER ≤ 29			
	1	8	↓			
	2	9	↑ SYMB. ADDRESS 9			
	3	9	↓			
	4	EC 176	1 LINE OF DOTS			....
	5	RESUME	√ END S.R. PRINT I [↓()]			
	6	$e^x/10^x$	↑ SUBROUTINE "f"; ($e^x/10^x$)			
	7	$e^x/10^x$	↓			
	8	f() ()				
	9	3				
1 1 3	0	2	T_e'			
	1	÷				
	2	f() ()				
	3	2				
	4	1	T_i			
	5	=	T_e'/T_i			
	6	ln/log	$\ln(T_e'/T_i)$			
	7	x				
	8	f() ()				
	9	2				
1 1 4	0	9	R_g/J			
	1	CHSGN	$-R_g/J$			
	2	÷	$-(R_g/J) \ln(T_e'/T_i)$			
	3	(				
	4	f() ()				
	5	3				
	6	1	φ_e'			
	7	-				
	8	f() ()				
	9	3				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
115	0	0	φ_i			
	1	)	$\varphi_e' - \varphi_i$			
	2	+				
	3	1				
	4	=	$1 - \frac{R_g}{J} \ln \left(\frac{T_e'}{T_i} \right)$			
	5	$1/x$	$\varphi_e' - \varphi_i$			
	6	$\downarrow () ()$				
	7	2				
	8	8			$\bar{y} \rightarrow 28$	
	9	$\uparrow () ()$				
116	0	1				
	1	0	J			
	2	$\downarrow () ()$				
	3	X				
	4	2				
	5	9	$R_g/J \rightarrow R_g$		$R_g \rightarrow 29$	
	6	RESUME	$\downarrow$ END S.R. $\bar{y} (e^*/10^3)$			
	7	$\div$	$\uparrow$ SUBROUTINE "COMPRESSOR" ($\div$)		$P_e/P_i \rightarrow 20$	
	8	$\div$	$\downarrow$		$T_i \rightarrow 21$	
	9	0	$f = 0$		$\eta_c \rightarrow 23$	
					$P.I. \rightarrow 36$	
117	0	$\downarrow ()$				
	1	5			$f = 0 \rightarrow 5$	
	2	$\downarrow () ()$				
	3	2				
	4	7			$f = 0 \rightarrow 27$	
	5	$\uparrow () ()$				
	6	2				
	7	1	T_i			
	8	$\downarrow ()$				
	9	0			$T_i \rightarrow 0$	
118	0	BRANCH	$\uparrow$ TO S.R. "h," (+) For $h_i = f(T_i)$			
	1	IND/SYMB	$\downarrow$			
	2	+	h_i			
	3	$\downarrow () ()$				
	4	2				
	5	2			$h_i \rightarrow 22$	
	6	BRANCH	$\uparrow$ TO S.R. " φ " (-) For $\varphi_i = f(T_i)$			
	7	IND/SYMB	$\downarrow$			
	8	-	φ_i			
	9	$\downarrow () ()$				
119	0	3				
	1	0			$\varphi_i \rightarrow 30$	
	2	BRANCH	$\uparrow$ TO S.R. " R_g/J " ($\sqrt{\quad}$) for $f = 0$			
	3	IND/SYMB	$\downarrow$			
	4	$\sqrt{\quad}$	R_g/J			
	5	X				
	6	(				
	7	$\uparrow () ()$				
	8	2				
	9	0	P_e/P_i			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 2 0	0	ln / log	$\ln (P_e/P_i)$			
	1	)				
	2	+	$(R_0/J) \ln (P_e/P_i)$			
	3	$\uparrow () ()$				
	4	3				
	5	0	φ_i			
	6	=	φ_e'			
	7	$\downarrow () ()$				
	8	3				
	9	1			$\varphi_e' \rightarrow 31$	
1 2 1	0	4	IND/SYMB $\uparrow$ SYMBOL. ADDRESS 4			
	1	4	$\downarrow$			
	2	HALT	ENTER: $T^* = T_e'$ FOR ITERATION IN φ_e'	$T^* = T_e'$		
	3	$\downarrow () ()$				
	4	3				
	5	2	$T^* = T_e'$		$T_e' \rightarrow 32$	
	6	$\downarrow ()$				
	7	0			$T^* \rightarrow 0$	
	8	BRANCH	$\uparrow$ TO S.R. " φ " (-) FOR $\varphi^* = f(T^*, f=0)$			
	9	IND/SYMB	$\downarrow \varphi^*$			
1 2 2	0	=	φ^*			
	1	-				
	2	$\uparrow () ()$				
	3	3				
	4	1	φ_e'			
	5	=	$\varphi^* - \varphi_e' = \Delta\varphi$			
	6	2	$\uparrow$			
	7	0				
	8	.	P.I. 20.			
	9	EC 177	$\downarrow$			20.
1 2 3	0	PRINT A				$\Delta\varphi$
	1	$\uparrow ()$				
	2	0	T^*			
	3	PRINT A				T^*
	4	HALT	IF $\Delta\varphi \leq 0$: ENTER Q: 0			
	5	JUMP	$\uparrow$			
	6	=	GO TO S.A. 5: IF $\Delta\varphi = 0$			
	7	IND/SYMB	$\downarrow$			
	8	5				
	9	JUMP	$\uparrow$ GO TO S.A. 4 IF $\Delta\varphi \neq 0$ FOR			
1 2 4	0	IND/SYMB	IMPROVED $T^* = T_e'$			
	1	4	$\downarrow$			
	2	5	IND/SYMB $\uparrow$ SYMBOL. ADDRESS 5			
	3	5	$\downarrow$			
	4	$\uparrow () ()$	A			
	5	3	Unnecessary!			
	6	2	$T_e' \downarrow$			
	7	BRANCH	$\uparrow$ GO TO S.R. " h "; FOR $h_e' = f(T_e', f=0)$			
	8	IND/SYMB	$\downarrow$			
	9	+	h_e'			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 2 5	0	-				
	1	$\uparrow() ()$				
	2	2				
	3	2	h_i			
	4	$\div$				
	5	$\uparrow() ()$				
	6	2				
	7	3	η_c			
	8	+	$h_e - h_i$			
	9	$\downarrow() ()$				
1 2 6	0	2				
	1	6			$h_e - h_i \rightarrow 26$	
	2	$\uparrow() ()$				
	3	2				
	4	2				
	5	=	h_e			
	6	$\downarrow() ()$				
	7	2				
	8	5			$h_e \rightarrow 25$	
	9	6	IND/SYMB $\uparrow$ SYMBOL. ADDRESS 6			
1 2 7	0	6	$\downarrow$			
	1	HALT	ENTER: $T^* = T_e$ FOR ITERATION FOR h_e	$T^* = T_e$		
	2	$\downarrow() ()$				
	3	2				
	4	4	$T^* = T_e$		$T_e \rightarrow 24$	
	5	$\downarrow()$				
	6	0			$T^* \rightarrow 0$	
	7	BRANCH	$\uparrow$ TO S.R. "h" (+); FOR $h^* = F(T^*, f=0)$			
	8	IND/SYMB	$\downarrow h^*$			
	9	+				
1 2 8	0	-				
	1	$\uparrow() ()$				
	2	2				
	3	5	h_e			
	4	=	$h^* - h_e = \Delta h$			
	5	2	$\uparrow$			
	6	1	P.I. 21			
	7	.	$\downarrow$			
	8	EC 177				21.
	9	PRINTA				Δh
1 2 9	0	$\uparrow()$				
	1	0	T^*			
	2	PRINTA				T^*
	3	HALT	IF $\Delta h \equiv 0$: ENTER: 0			
	4	JUMP	$\uparrow$			
	5	=	GO TO S.A. 7 IF $\Delta h = 0$			
	6	IND/SYMB	$\downarrow$			
	7	7				
	8	JUMP	$\uparrow$ GO TO S.A. 6 IF $\Delta h \neq 0$ FOR			
	9	IND/SYMB	IMPROVED $T^* = T_e$			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 3 0 0		6	↓ GO TO S.A. 6 FOR IMPROVED $T^* = T_c$			
1	7	IND/SYMB	↑ SYMBOL. ADDRESS 7			
2		7	↓			
3		BRANCH	↑ TO S.R. "f" ($e^x/10^x$)			
4		IND/SYMB	↓		$\bar{Y} \rightarrow 28$	
5		$e^x/10^x$	↓		$R_4 \rightarrow 29$	
6		BRANCH	↑ TO S.R. "PRINT I"			
7		IND/SYMB	↓			
8		↓ ()	↓			COMPR DATA
9		JUMP	↑			
1 3 1 0		FLAG 1	IF FLAG 1 IS SET JUMP TO EC 040			
1		IND/SYMB	(LOW COMP)			
2	EC	040				
3		JUMP	IF FLAG 1 IS NOT SET JUMP TO EC 041			
4		IND/SYMB	(HIGH COMP)			
5	EC	041	↓ END S.R. COMPR.			
6	X	IND/SYMB	↑ SUBROUTINE "EXPANSION" (X)		$P_e/P_i \rightarrow 20$	
7		X	↓		$T_i \rightarrow 21$	
8		↑ () ()			$\eta_e \rightarrow 23$	
9		2			$f \rightarrow 27$	
1 3 2 0		7	f			
1		↓ ()				
2		5			$f \rightarrow 5$	
3		BRANCH	↑ TO S.R. "R _G /J"			
4		IND/SYMB	↓			
5		$\sqrt{\quad}$	↓		$R_G/J \rightarrow 29$	
6		↑ () ()				
7		2				
8		1	T_i			
9		↓ ()				
1 3 3 0		0			$T_i \rightarrow 0$	
1		BRANCH	↑ TO S.R. "h" FOR $h_i = F(T_i, f)$			
2		IND/SYMB	↓			
3		+	h_i			
4		↓ () ()				
5		2				
6		2			$h_i \rightarrow 22$	
7		BRANCH	↑ TO S.R. "φ" FOR $\varphi_i = F(T_i, f)$			
8		IND/SYMB	↓			
9		-	φ_i			
1 3 4 0		↓ () ()				
1		3				
2		0			$\varphi_i \rightarrow 30$	
3		+	φ_i			
4		(				
5		↑ () ()				
6		2				
7		0	P_e/P_i			
8		ln / log	$\ln(P_e/P_i)$			
9		X				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 3 5	0	$\uparrow () ()$				
	1	2				
	2	9	R_G/J			
	3	)	$(R_G/J) \ln(P_e/P_i)$			
	4	=	φ_e'			
	5	$\downarrow () ()$				
	6	3				
	7	1			$\varphi_e' \rightarrow 31$	
	8	(	IND/SYMB $\uparrow$ SYMBOL. ADDRESS (			
	9	(	$\downarrow$			
1 3 6	0	HALT	ENTER: $T^* = T_e'$ FOR ITERATION IN φ_e'	$T^* = T_e'$		
	1	$\downarrow () ()$				
	2	3				
	3	2			$T_e' \rightarrow 32$	
	4	$\downarrow ()$				
	5	0			$T^* \rightarrow 0$	
	6	BRANCH	$\uparrow$ TO S.R. "Q" FOR $\varphi^* = F(T^*, f)$			
	7	IND/SYMB	$\downarrow \varphi^*$			
	8	-				
	9	-				
1 3 7	0	$\uparrow () ()$				
	1	3				
	2	1	φ_e'			
	3	=	$\varphi^* - \varphi_e' = \Delta\varphi$			
	4	3	$\uparrow$			
	5	0	P.I. 30			
	6	.				
	7	EC 177				30.
	8	PRINT A				$\Delta\varphi$
	9	$\uparrow ()$				
1 3 8	0	0	T^*			
	1	PRINT A				T^*
	2	HALT	IF $\Delta\varphi \cong 0$: ENTER: 0			
	3	JUMP	$\uparrow$			
	4	=	GO TO S.A.) IF $\Delta\varphi = 0$			
	5	IND/SYMB	$\downarrow$			
	6	)				
	7	JUMP	$\uparrow$ GO TO S.A. (IF $\Delta\varphi \neq 0$ FOR			
	8	IND/SYMB	IMPROVED $T^* = T_e'$			
	9	(	$\downarrow$			
1 3 9	0	)	IND/SYMB $\uparrow$ SYMBOL. ADDRESS)			
	1	)	$\downarrow$			
	2	BRANCH	$\uparrow$ TO S.R. "h" FOR $h_e' = F(T_e', f)$			
	3	IND/SYMB	$\downarrow h_e'$			
	4	+	$-h_e'$			
	5	CHSGN				
	6	+				
	7	$\uparrow () ()$				
	8	2				
	9	2	h_i			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 4 0	0	X	$h_i - h_e'$			
	1	$\uparrow() ()$				
	2	2				
	3	3	η_e			
	4	-	$(h_i - h_e') \eta_e = h_i - h_e$			
	5	$\downarrow() ()$				
	6	2				
	7	6			$h_i - h_e \rightarrow 26$	
	8	$\uparrow() ()$				
	9	2				
1 4 1	0	2	h_i			
	1	=	$-h_e$			
	2	CHSGN	h_e			
	3	$\downarrow() ()$				
	4	2				
	5	5			$h_e \rightarrow 25$	
	6	$\uparrow$ IND/SYMB	$\uparrow$ SYMBOL. ADDRESS $\rightarrow$			
	7	$\uparrow$	$\downarrow$			
	8	HALT	ENTER: $T^* = T_e$ FOR ITERATION IN h_e	$T^* = T_e$		
	9	$\downarrow() ()$				
1 4 2	0	2				
	1	4			$T_e \rightarrow 24$	
	2	$\downarrow()$				
	3	0			$T^* \rightarrow 0$	
	4	BRANCH	$\uparrow$ TO S.R. "h" FOR $h^* = F(T^*, t)$			
	5	IND/SYMB	$\downarrow h^*$			
	6	+				
	7	-				
	8	$\uparrow() ()$				
	9	2				
1 4 3	0	5	h_e			
	1	=	$h^* - h_e = \Delta h$			
	2	3	$\uparrow$			
	3	1	P.I. 31.			
	4	.	$\downarrow$			
	5	EC 177				31.
	6	PRINT A				Δh
	7	$\uparrow()$				
	8	0	T^*			
	9	PRINT A				T^*
1 4 4	0	HALT	IF $\Delta h \cong 0$: ENTER: 0			
	1	JUMP	$\uparrow$			
	2	=	IF $\Delta h = 0$ GO TO S.A. X			
	3	IND/SYMB	$\downarrow$			
	4	X				
	5	JUMP	$\uparrow$ GO TO S.A. $\rightarrow$ IF $\Delta h \neq 0$ FOR			
	6	IND/SYMB	IMPROVED $T^* = T_e$			
	7	$\uparrow$	$\downarrow$			
	8	X IND/SYMB	$\uparrow$ SYMBOL. ADDRESS X			
	9	X	$\downarrow$			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
145	0	BRANCH	↑ TO S.R. "f"			
	1	IND/SYMB	↓		$\bar{v} \rightarrow 28$	
	2	$e^x/10^x$	↓		$R_G \rightarrow 29$	
	3	BRANCH	↑ TO S.R. " $(V_e)_e, a_e$ "			
	4	IND/SYMB	↓		$(V_e)_e \rightarrow 33$	
	5	ln/LOG	↓		$a_e \rightarrow 35$	
	6	f() ()				
	7	2				
	8	6	$h_i - h_e$			
	9	X				
146	0	f() ()				
	1	1				
	2	8	$2gJ$			
	3	=	$V_d^2 = 2gJ(h_i - h_e)$			
	4	$\sqrt{\quad}$	V_d			
	5	↓() ()				
	6	3				
	7	4			$V_d \rightarrow 34$	
	8	÷				
	9	f() ()				
147	0	3				
	1	5	a_e			
	2	=	$M_d = V_d/a_e$			
	3	↓() ()				
	4	3				
	5	5			$M_d \rightarrow 35$	
	6	BRANCH	↑			
	7	IND/SYMB	↑ TO S.R. "PRINT I"			
	8	↓()	↓			DATA
	9	JUMP	↑			
148	0	FLAG	IF FLAG 1 IS SET JUMP TO EC 044			
	1	IND/SYMB	(LOW TURBINE)			
	2	EC 044	↓			
	3	JUMP	↑			
	4	IND/SYMB	IF FLAG 1 IS NOT SET JUMP TO EC 046			
	5	EC 046	↓ (JET NOZZLE)		END S.R. "EXPANSION"	
	6	ln/LOG	↑ SUBROUTINE " $(V_e)_e, a_e$ "; (ln/LOG)			
	7	ln/LOG	↓ USE AFTER S.R. "f"; ($e^x/10^x$)			
	8	f() ()				
	9	2				
149	0	4	T_e			
	1	÷				
	2	f() ()				
	3	2				
	4	5	h_e			
	5	X				
	6	f() ()				
	7	2				
	8	9	R_G			
	9	÷				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
150	0	$\uparrow()()$				
1		1				
2		0	J			
3		CHSGN	-J			
4		+				
5		1	1			
6		=	$1 - (R_0/J) T_e / h_e$			
7		$1/x$	$(V_e)_e$			
8		$\downarrow()()$				
9		3				
151	0	3			$(V_e)_e \rightarrow 33$	
1		x				
2		$\uparrow()()$				
3		1				
4		6	g			
5		x				
6		$\uparrow()()$				
7		2				
8		9	R_0			
9		x				
152	0	$\uparrow()()$				
1		2				
2		4	T_e			
3		=	$(V_e)_e g R_0 T_e = a_e^2$			
4		$\sqrt{\quad}$	a_e			
5		$\downarrow()()$				
6		3				
7		5			$a_e \rightarrow 35$	
8		RESUME	$\sqrt{\quad}$ END S.R. " $(V_e)_e, a_e$ "			
9	π/e	IND/SYMB	SUBROUTINE ".HT" (π/e)		$\Delta h = h_i - h_e \rightarrow 26$	
153	0	π/e			$T_i \rightarrow 21$	
1		$\uparrow()()$			$\eta \rightarrow 23$	
2		2			$f \rightarrow 27$	
3		1	T_i		P.I. $\rightarrow 36$	
4		$\downarrow()$				
5		0			$T_i \rightarrow 0$	
6		$\uparrow()()$				
7		2				
8		7	f			
9		$\downarrow()$				
154	0	5			$f \rightarrow 5$	
1		BRANCH	$\uparrow$ TO S.R. " R_0/J " (Γ)			
2		IND/SYMB	$\downarrow$			
3		$\sqrt{\quad}$			$R_0/J \rightarrow 29$	
4		BRANCH	$\uparrow$ TO S.R. " φ " (-) FOR $\varphi_i = F(T_i, f)$			
5		IND/SYMB	$\downarrow$			
6		-	φ_i			
7		$\downarrow()()$				
8		3				
9		0			$\varphi_i \rightarrow 30$	

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 5 5	0	BRANCH	↑			
	1	IND/SYMB	TO S.R. "h" (+) FOR $h_i = F(T_i, f)$			
	2	+	↓ h_i			
	3	↓ () ()				
	4	2				
	5	2			$h_i \rightarrow 22$	
	6	-				
	7	↑ () ()				
	8	2				
	9	6	$\Delta h = h_i - h_e$			
1 5 6	0	=	h_e			
	1	↓ () ()				
	2	2				
	3	5			$h_e \rightarrow 25$	
	4	2NDFUNC	↑ SYMBOL. ADDRESS 2NDFUNC			
	5	2NDFUNC	↓			
	6	HALT	ENTER: $T^* = T_e$ FOR ITERATION IN h_e	$T^* = T_e$		
	7	↓ () ()				
	8	2				
	9	4			$T_e \rightarrow 24$	
1 5 7	0	↓ () ()				
	1	3				
	2	2			$T_e \rightarrow 32$	
	3	↓ ()				
	4	0			$T^* \rightarrow 0$	
	5	BRANCH	↑			
	6	IND/SYMB	TO S.R. "h" (+) FOR $h^* = F(T^*, f)$			
	7	+	↓ h^*			
	8	-				
	9	↑ () ()				
1 5 8	0	2				
	1	5	h_e			
	2	=	$\Delta h = h^* - h_e$			
	3	4	↑			
	4	0	P.I. 40.			
	5	.	↓			
	6	EC 177				40.
	7	PRINT A				Δh
	8	↑ ()				
	9	0	T^*			
1 5 9	0	PRINT A				T^*
	1	HALT	IF $\Delta h \geq 0$: ENTER: 0			
	2	JUMP	↑			
	3	=	IF $\Delta h = 0$ GO TO S.A. $1/x$			
	4	IND/SYMB	↓			
	5	$1/x$				
	6	JUMP	↑ IF $\Delta h \neq 0$ GO TO S.A. 2NDFUNC			
	7	IND/SYMB	FOR IMPROVED $T^* = T_e$			
	8	2NDFUNC	↓			
	9	$1/x$ IND/SYMB	SYMBOL. ADDRESS $1/x$			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 6 0 0		1/x				
1		↑() ()				
2		2				
3		6	$h_i - h_e$			
4		÷				
5		↑() ()				
6		2				
7		3	η			
8		CHSGN	$-\eta$			
9		+	$-(h_i - h_e)/\eta$			
1 6 1 0		↑() ()				
1		2				
2		2	h_i			
3		-	$h_e' = h_i - (h_i - h_e)/\eta$			
4		↓() ()				
5		3				
6		4			$h_e' \rightarrow 34$	
7		↑() ()				
8		2				
9		5	h_e			
1 6 2 0		=	$h_e' - h_e$			
1		JUMP	↑			
2		=	IF $h_e' = h_e$ JUMP TO S.A. $R \rightarrow 0$			
3		IND/SYMB	↓			
4		$R \rightarrow 0$				
5	SIN/COS	IND/SYMB	↑ SYMBOL. ADDRESS SIN/COS			
6		SIN/COS	↓			
7		HALT	ENTER: $T^* = T_e'$ FOR ITERATION IN h_e' $T^* = T_e'$			
8		↓() ()				
9		3				
1 6 3 0		2			$T_e' \rightarrow 32$	
1		↓()				
2		0			$T^* \rightarrow 0$	
3		BRANCH	↑ TO SUB.R. " $h^*(+)$ FOR $h^* = F(T^*, f)$ "			
4		IND/SYMB	↓			
5		+	h^*			
6		-				
7		↑() ()				
8		3				
9		4	h_e'			
1 6 4 0		=	$\Delta h = h^* - h_e'$			
1		4	↑			
2		1	P.I. 41.			
3		.	↓			
4	EC	177				41.
5		PRINTA				Δh
6		↑()				
7		0	T^*			
8		PRINTA				T^*
9		HALT	IF $\Delta h \leq 0$: ENTER: 0			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 6 5 0		JUMP	↑			
1	=		IF $\Delta h = 0$ GO TO S.A. $R \rightarrow 0$			
2	IND/SYMB		↓			
3	$R \rightarrow 0$		↓			
4	JUMP		↑ IF $\Delta h \neq 0$ GO TO S.A. SIN/COS FOR			
5	IND/SYMB		IMPROVED $T^* = T_e'$			
6	SIN/COS		↓			
7 $R \rightarrow 0$	IND/SYMB		↑ SYMBOL. ADDRESS $R \rightarrow 0$			
8	$R \rightarrow 0$		↓			
9	BRANCH		↑ TO S.R. " φ " (-) FOR $\varphi_e' = F(T_e', f)$			
1 6 6 0		IND/SYMB	↓ φ_e'			
1	-		↓ φ_e'			
2	↓() ()					
3	3					
4	1	φ_e'			$\varphi_e' \rightarrow 31$	
5	-					
6	↑() ()					
7	3					
8	0	φ_i				
9	÷	$\varphi_e' - \varphi_i$				
1 6 7 0		↑() ()				
1	2					
2	9	R_a/J				
3	=	$(\varphi_e' - \varphi_i) / (R_a/J)$				
4	$e^x / 10^x$	$P_e / P_i = e^{(\varphi_e' - \varphi_i) / (R_a/J)}$				
5	↓() ()					
6	2					
7	0				$P_e / P_i \rightarrow 20$	
8	BRANCH	↑ TO S.R. " $\bar{Y}$ " ($e^x / 10^x$)				
9	IND/SYMB	↓			$\bar{Y} \rightarrow 28$	
1 6 8 0		$e^x / 10^x$	↓		$R_a \rightarrow 29$	
1	BRANCH	↑ TO S.R. " $(\varphi_e)_e, a_e$ " ($\ln / \log$)				
2	IND/SYMB	↓			$(\varphi_e)_e \rightarrow 33$	
3	$\ln / \log$				$a_e \rightarrow 35$	
4	BRANCH	↑ TO S.R. "PRINT I" [↓()]				
5	IND/SYMB	↓				
6	↓()					DATA
7	JUMP	↑ IF FLAG 1 IS SET JUMP TO EC 042				
8	FLAG	(HIGH TURBINE)				
9	IND/SYMB	↓				
1 6 9 0	EC	042	↓			
1	JUMP	↑ IF FLAG 1 IS NOT SET JUMP TO EC 047				
2	IND/SYMB	(INLET DUCT				
3	EC	047	↓			
			↑ (END S.R. "HT")			
4	↑()	IND/SYMB	↑ SUBROUTINE "PRINT II" [↑()]			
5	↑()		↓			
6	↑() ()					
7	2					
8	5	T_e				
9	↑() ()					

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
170	0	2				
	1	9	RCL P.I.			
	2	EC 177				P.I.
	3	PRINT A				T_e
	4	$\uparrow()()$				
	5	2				
	6	6	h_e			
	7	PRINT A				h_e
	8	$\uparrow()()$				
	9	2				
171	0	7	Δf or $\zeta = \dot{w}_i / w_i$			
	1	PRINT A				Δf or ζ
	2	$\uparrow()()$				
	3	2	S.R. "PRINT I"			
	4	8	f_e [$\uparrow()$]			
	5	PRINT A				f_e
	6	EC 176	1 LINE OF DOTS			....
	7	RESUME				
	8	a^* IND/SYMB	$\uparrow$ SUBROUTINE "BURNER" (a^*)		$T_i \rightarrow 20$ $f_i \rightarrow 21$ $T_e \rightarrow 25$	
	9	a^*	$\downarrow$		$T_i \rightarrow 22$ $P.I. \rightarrow 29$	
172	0	$\uparrow()()$				
	1	2				
	2	0	T_i			
	3	$\downarrow()$				
	4	0			$T_i \rightarrow 0$	
	5	BRANCH	$\uparrow$ TO S.R. "h" (+) FOR $(h_A)_i = F(T_i)$			
	6	IND/SYMB	$\downarrow$ $(h_G)_i = F(T_i)$			
	7	+				
	8	$\uparrow()$				
	9	6	$(h_A)_i$			
173	0	$\downarrow()()$				
	1	2				
	2	3			$(h_A)_i \rightarrow 23$	
	3	$\uparrow()$				
	4	7	$(h_G)_i$			
	5	$\downarrow()()$				
	6	2				
	7	4			$(h_G)_i \rightarrow 24$	
	8	$\uparrow()()$				
	9	2				
174	0	5	T_e			
	1	$\downarrow()$				
	2	0			$T_e \rightarrow 0$	
	3	BRANCH	$\uparrow$ TO S.R. "h" (+) FOR $(h_A)_e = F(T_e)$			
	4	IND/SYMB	$\downarrow$ $(h_A)_e = F(T_e)$			
	5	+				
	6	$\uparrow()$				
	7	6	h_{Ae}			
	8	-				
	9	$\uparrow()()$				

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
175	0	2				
	1	3	h_{Ai}			
	2	+	$h_{Ae} - h_{Ai}$			
	3	(				
	4	$\uparrow()$				
	5	2				
	6	1	f_i			
	7	x				
	8	(				
	9	$\uparrow()$				
176	0	7	h_{Ae}			
	1	-				
	2	$\uparrow()$				
	3	2				
	4	4	h_{Ai}			
	5	)	$h_{Ae} - h_{Ai}$			
	6	)	$f_i(h_{Ae} - h_{Ai})$			
	7	$\div$				
	8	(				
	9	$\uparrow()$				
177	0	0				
	1	9	h_f			
	2	+				
	3	(				
	4	$\uparrow()$				
	5	2				
	6	2	γ_B			
	7	x				
	8	$\uparrow()$				
	9	0				
178	0	8	LHV			
	1	)				
	2	-				
	3	$\uparrow()$				
	4	7	h_{Ae}			
	5	)	$h_f + \gamma_B LHV - h_{Ae}$			
	6	+	Δf			
	7	$\downarrow()$				
	8	2				
	9	7			$\Delta f \rightarrow 27$	
179	0	$\uparrow()$				
	1	2				
	2	1	f_i			
	3	x	$f_e = \Delta f + f_i$			
	4	$\downarrow()$				
	5	2				
	6	8			$f_e \rightarrow 28$	
	7	$\uparrow()$				
	8	7	h_{Ae}			
	9	+	$f_e h_{Ae}$			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1 8 0	0	$\uparrow ()$				
	1	6	h_{Ae}			
	2	$\div$	$h_{Ae} + f_e h_{Ae}$			
	3	(				
	4	1	1			
	5	+				
	6	$\uparrow () ()$				
	7	2				
	8	8	f_e			
	9	)	$1 + f_e$			
1 8 1	0	=	h_e			
	1	$\downarrow () ()$				
	2	2				
	3	6			$h_e \rightarrow 26$	
	4	BRANCH	$\uparrow$ TO S.R. "PRINT II" [$\uparrow ()$]			DATA
	5	IND/SYMB	$\downarrow$			
	6	$\uparrow ()$				
	7	RESUME	$\downarrow$ END S.R. "BURNER" (α^*)			
	8	Φ	IND/SYMB SUBROUTINE "MIXING" (Φ)		$T_{ii} \rightarrow 20$ $f_i \rightarrow 21$ $T_{ii} \rightarrow 22$ $f_{ii} \rightarrow 23$ $\Phi \rightarrow 27$ $PI \rightarrow 29$	
	9	Φ				
1 8 2	0	$\uparrow () ()$				
	1	2				
	2	0	T_i			
	3	$\downarrow ()$				
	4	0			$T_i \rightarrow 0$	
	5	$\uparrow () ()$				
	6	2				
	7	1	f_i			
	8	$\downarrow ()$				
	9	5			$f_i \rightarrow 5$	
1 8 3	0	BRANCH	$\uparrow$ TO S.R. "h" FOR $h_i = F(T_i, f_i)$			
	1	IND/SYMB	$\downarrow h_i$			
	2	+				
	3	x				
	4	(				
	5	1				
	6	+				
	7	$\uparrow () ()$				
	8	2				
	9	1	f_i			
1 8 4	0	)	$1 + f_i$			
	1	=	$(1 + f_i) h_i$			
	2	$\downarrow () ()$				
	3	2				
	4	4			$(1 + f_i) h_i \rightarrow 24$	
	5	$\uparrow () ()$				
	6	2				
	7	2	T_{ii}			
	8	$\downarrow ()$				
	9	0			$T_{ii} \rightarrow 0$	

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
185	0	$\uparrow () ()$				
	1	2				
	2	3	f_{ii}			
	3	$\downarrow ()$				
	4	5			$f_{ii} \rightarrow 5$	
	5	BRANCH	$\uparrow$ TO S.R. "h" FOR $h_{ii} = F(T_{ii}; f_{ii})$			
	6	IND/SYMB	$\downarrow$			
	7	+	h_{ii}			
	8	X				
	9	$\uparrow () ()$				
186	0	2				
	1	7	ξ			
	2	X	ξh_{ii}			
	3	(				
	4	1	1			
	5	+				
	6	$\uparrow () ()$				
	7	2				
	8	3	f_{ii}			
	9	)	$1 + f_{ii}$			
187	0	+	$\xi h_{ii} (1 + f_{ii})$			
	1	$\uparrow () ()$				
	2	2				
	3	4	$(1 + f_{ii}) h_{ii}$			
	4	$\div$	$(1 + f_{ii}) h_{ii} + \xi h_{ii} (1 + f_{ii})$			
	5	(				
	6	1	1			
	7	+				
	8	$\uparrow () ()$				
	9	2				
188	0	7	ξ			
	1	+	$1 + \xi$			
	2	$\downarrow ()$				
	3	6			$1 + \xi \rightarrow 6$	
	4	(				
	5	$\uparrow () ()$				
	6	2				
	7	7	ξ			
	8	X				
	9	$\uparrow () ()$				
189	0	2				
	1	3	f_{ii}			
	2	+	ξf_{ii}			
	3	$\uparrow () ()$				
	4	2				
	5	1	f_i			
	6	)	$f_i + \xi f_{ii}$			
	7	$\downarrow ()$				
	8	7			$f_i + \xi f_{ii} \rightarrow 7$	
	9	)	$1 + \xi + f_i + \xi f_{ii}$			

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
1900		=	h_e			
1		$\downarrow () ()$				
2		2				
3		6			$h_e \rightarrow 26$	
4		$\uparrow ()$				
5		7	$f_i + 3 f_{ii}$			
6		$\div$				
7		$\uparrow ()$				
8		6	$1 + 3$			
9		=	f_e			
1910		$\downarrow () ()$				
1		2				
2		8			$f_e \rightarrow 28$	
3		$\downarrow ()$				
4		5			$f_e \rightarrow 5$	
5		$\uparrow () ()$				
6		2				
7		0	T_i			
8		$\downarrow () ()$				
9		2				
1920		5	SET $T_e = T_i$ IF $T_i = T_{ii}$		$T_i = T_e \rightarrow 25$	
1		-				
2		$\uparrow () ()$				
3		2				
4		2	T_{ii}			
5		=	$T_i - T_{ii}$			
6		JUMP	$\uparrow$ TO S.A. Σ_0 IF $T_i = T_{ii}$			
7		=	TO S.A. 1 IF $T_i \neq T_{ii}$			
8		IND/SYMB				
9		Σ_0				
1930	1	IND/SYMB	$\uparrow$ SYMBOL ADDRESS 1			
1		1	$\downarrow$			
2		HALT	ENTER: $T^* = T_e$ FOR ITERATION IN h_e	$T^* = T_e$		
3		$\downarrow () ()$				
4		2				
5		5			$T_e \rightarrow 25$	
6		$\downarrow ()$				
7		0			$T^* \rightarrow 0$	
8		BRANCH	$\uparrow$ TO S.R. "h" FOR $h^* = F(T^*, f_e)$			
9		IND/SYMB				
1940		+	h^*			
1		-				
2		$\uparrow () ()$				
3		2				
4		6	h_e			
5		=	$\Delta h = h^* - h_e$			
6		1	$\uparrow$			
7		0	P.I. 10.			
8		.				
9	EC	177	$\downarrow$			10.

STEP	SYMBOL	COMMAND	COMMENTS	ENTER	STORE	PRINT
195	0	PRINT A				dh
	1	$\uparrow ()$				
	2	0	T*			
	3	PRINT A				T*
	4	HALT	IF $\Delta h \cong 0$: ENTER : 0			
	5	JUMP	$\uparrow$			
	6	=	IF $\Delta h = 0$ GO TO S.A. Σ_0			
	7	IND/SYMB	$\downarrow$			
	8	Σ_0				
	9	JUMP	$\uparrow$ IF $\Delta h \neq 0$ GO TO S.A. 1 FOR			
196	0	IND/SYMB	IMPROVED $T^* = T_c$			
	1	1	$\downarrow$			
	2	Σ_0	$\uparrow$ SYMBOL. ADDRESS Σ_0			
	3	Σ_0	$\downarrow$			
	4	BRANCH	A TO S.R. "PRINT II"			DATA
	5	IND/SYMB	$\downarrow$			
	6	$\uparrow ()$				
	7	JUMP	$\uparrow$ IF FLAG 1 IS SET JUMP TO EC 043			
	8	FLAG 1	(MIXING AFTER HT)			
	9	IND/SYMB	$\downarrow$			
197	0	EC 043				
	1	JUMP	$\uparrow$ IF FLAG 1 IS NOT SET JUMP TO			
	2	IND/SYMB	S.A. EC 045	END	S.R. MIXING	
	3	EC 045	$\downarrow$ (MIXING AFTER D.B. & A.B.)	END	PROGRAM 514	
	4					
	5					
	6					
	7					
	8					
	9					
198	0					
	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					
	0					
	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					

SCRATCH PAD MEMORY STORAGE

[illegible]

MAIN STORAGE BOOKKEEPING

REGISTER	CONTENTS 1	CONTENTS 2	CONTENTS 3
0 0	J/R = 778.16/1545.43 ↑		
1	C ₁		
2	C ₂		
3	C ₃ ENTERED		
4	C ₄ BY PROG.		
5	C ₅ VA 513		
6	a = .034522		
7	b = .035648		
8	LHV = 18,400		
9	h _f = 260		
1 0	J = 778.16		
1	D ₁		
2	D ₂		
3	D ₃		
4	D ₄		
5	D ₅		
6	g = 32.174		
7	J/550		
8	2gJ ↓		
9			
2 0	P _e /P _i (INPUT) ↑	P _e /P _i (INPUT) ↑	P _e /P _i ↑
1	T _i (INPUT) ↑	T _i (INPUT) ↑	T _i (INPUT) PRINT-OUT
2	h _i	h _i PRINT-OUT	h _i "PRINT I"
3	η _c (INPUT) PRINT-OUT	η _e (INPUT) "PRINT I"	η (INPUT) ↓ ()
4	T _e "PRINT I"	T _e SUB.ROUT [K]	T _e SUB.ROUT
5	h _e ↓ ()	h _e "EXPANS"	h _e "HT"
6	h _e - h _i	h _i - h _e (X)	h _i - h _e (INPUT) (V/e)
7	f = 0 SUB.ROUT	f (INPUT)	f (INPUT)
8	γ "COMPR"	γ	γ
9	R _a /J R _G (÷) ↓	R _a /J R _G ↓	R _a /J R _G ↓
3 0	φ _i	φ _i	φ _i
1	φ _e '	φ _e '	φ _e '
2	T _e '	T _e '	T _e '
3		(V _e) _e	(V _e) _e
4		V _d	h _e '
5		a _e | M _d	a _e
6	PRINT IDENTIF.	PRINT IDENT.	PRINT IDENT.
7	POINTER ↓	POINTER ↓	POINTER ↓
8			
9			
4 0	(SEE PAGE 52)		
1			
2			
3			
4			
5			
6			
7			
8			
9			

MAIN STORAGE BOOKKEEPING

REGISTER	CONTENTS 4 (20-29)	CONTENTS 5 (20-29)	CONTENTS 6 (20-29)
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
2 0	T_i (INPUT) ↑	T_i (INPUT) ↑	
1	f_i (INPUT) ↑	f_i (INPUT) ↑	
2	γ_B (INPUT) ↑	T_{ii} (INPUT) ↑	
3	h_{Ai} SUBROUT	f_{ii} (INPUT) SUBROUT	
4	h_{Gi} "BURNER"	$h_i(1+f_i)$ "MIXING"	
5	T_e (INPUT) (a^*) ↑	T_e (Φ) ↓	I_{sp} ↑
6	h_e PRINT-OUT	h_e PRINT-OUT "PRINT II"	SFC OVERALL "PRINT II"
7	Δf "PRINT II"	ξ (INPUT) [$\uparrow$ ()]	b PERFORM. [$\uparrow$ ()]
8	f_e ↓ [$\uparrow$ ()]	f_e ↓	M_d ↓
9	PRINT IDENT. ↓	PRINT IDENT. ↓	PRINT IDENT. - 200
0			
1			
2			
3			
4			
5			
6			
7			
8			
9	CONTENTS 1 (40-49)		
4 0	P_0 ↑		
1	T_0		
2	P_2/P_1 ENTERED		
3	P_3/P_1 BY PROG.		
4	T_4 VA 513		
5	$T_9 = T_{10}$		
6	ξ		
7	λ_I		
8	λ_{BP}		
9	λ_B		

MAIN STORAGE BOOKKEEPING

REGISTER		CONTENTS 1	CONTENTS 2	CONTENTS 3
5	0	$\lambda_{DB} = \lambda_{AB}$		
	1	γ_{LC}		
	2	γ_{HC}		
	3	γ_{HT} ENTERED		
	4	γ_{LT} BY PROG.		
	5	γ_B VA 513		
	6	γ_{AB}		
	7	ψ_N ↓		
	8			
	9	POINTER		
6	0	D_{Ti} ↑ ↑		
	1	r_{hi} ↑		
	2	U_T INPUT		
	3	β_{iT} ↓		
	4	k_i ↓ PRINT-OUT		
	5	F		
	6	$\dot{w}$		
	7	HP_{LC}		
	8	HP_{HC}		
	9	$M_{W1} = W_1/a_1$ ↓		
7	0	$h_2 - h_1$		
	1	$h_3 - h_2$		
	2	T_3		
	3	f_B'		
	4	P_5/P_4		
	5	T_5		
	6	P_8/P_5		
	7	f_B		
	8	$h_6 - h_8$		
	9	b		
8	0	T_8		
	1	Δf_{AB}		
	2	$f_e = f_B + \Delta f_{AB}$		
	3	T_2		
	4	f_N		
	5	I_{SP}		
	6			
	7			
	8			
	9			
9	0	$\sin \beta_{iT}$		
	1	$U_T \cot \beta_{iT}$		
	2	$C = \pi/4 D_{Ti}^2 (1 - r_{hi}^2) k_i$		
	3			
	4			
	5			
	6			
	7			
	8			
	9			

DISTRIBUTION LIST

	<u>No. of Copies</u>
1. Defense Documentation Center Cameron Station Alexandria, Virginia 22314	12
2. Library Code 0212 Naval Postgraduate School Monterey, California 93940	2
3. Superintendent Code 00 Naval Postgraduate School Monterey, California 93940	1
4. Provost Code 02 Naval Postgraduate School Monterey, California 93940	1
5. Dean of Research Code 023 Naval Postgraduate School Monterey, California 93940	1
6. Chairman Department of Aeronautics Code 57 Naval Postgraduate School Monterey, California 93940	1
7. Turbo-Propulsion Laboratory Department of Aeronautics Naval Postgraduate School Monterey, California 93940	20
8. Commanding Officer Naval Air Systems Command Navy Department Washington, D.C. 20360	1
9. Dr. H. J. Mueller Research Administrator Code 310A Naval Air Systems Command Navy Department Washington, D.C. 20360	2

10. Mr. E. A. Lichtman
Naval Air Systems Command
Code 330
Navy Department
Washington, D.C. 20360 1

11. Mr. Karl H. Guttman
Code 330C
Naval Air Systems Command
Navy Department
Washington, D.C. 20360 1

12. Acquisition Inf
Code AIR - 50174 14

13. Rear Admiral C. O. Holmquist, USN
Chief of Naval Research
Office of Naval Research
Arlington, Virginia 22218 1

14. Commanding Officer
Naval Air Propulsion Test Center
Attn: Mr. E. Stawski
Trenton, New Jersey 08628 1

15. Mr. Eric Lister
R & T Division
Naval Air Propulsion Test Center
Trenton, New Jersey 08628 1

16. National Aeronautics and Space Administration
Lewis Research Center (Library)
2100 Brookpark Road
Cleveland, Ohio 44135 1

17. Library
General Electric Company
Aircraft Engine Technology Division
DTO Mail Drop H43
Cincinnati, Ohio 45215 1

18. Library
Pratt and Whitney Aircraft
Post Office Box 2691
West Palm Beach, Florida 33402 1

19. Library
Pratt and Whitney Aircraft
East Hartford, Connecticut 06108 1

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NPS-57Va73061A	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Calculating Procedure of Sea-Level Static Performance of Two-Spool Afterburning Bypass Jet Engine		5. TYPE OF REPORT & PERIOD COVERED Progress Report (July 1973)
7. AUTHOR(s) Michael H. Vavra		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Aeronautics Naval Postgraduate School Monterey, California 93940		8. CONTRACT OR GRANT NUMBER(s) Air Task No. A 310 310A/186A/3R02403001 Ref. b
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Systems Command AIR-310		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N.A.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE June 1973
		13. NUMBER OF PAGES 106
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release, distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Electronic Programmable Calculator Programs Jet Engine SLS Performance Prediction Bypass Engine After- and Duct Burning Engine Real Gas Effects Jet Engine Diameter for Specified Thrust		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A calculating procedure is presented for the sea-level static performance of duct burning and afterburning bypass jet engines that have a low pressure and a high pressure spool. Performance values can be determined also for operation without reheat. Influence of temperature and fuel/air ratio on the thermodynamic properties of air and combustion gases is taken into account. A calculating program for a Monroe 1880-43 programmable electronic desk calculator is described which makes it possible to evaluate effects of changes of parameters on performance with minimum effort. (continued)		

DD FORM 1473
1 JAN 73
(Page 1)EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20.

The program will be used to establish the characteristics of compressors required for propulsive units of later generation Navy air-superiority fighter aircraft, to investigate whether the Turbo-Propulsion Laboratory of NPS would be capable of undertaking research and development work of such machines.

Programs of the type presented, and the use of modern programmable desk calculators, will also be of great value for instructional purposes. Teachers can then concentrate on the fundamental nature of particular topics and need not waste time on lengthy derivations, or on simplifications and approximations that are introduced only to solve equations with elementary means. The students would be relieved of the drudgery of routine hand calculations that do not contribute to a better understanding of the subject matter.

U159888

DUDLEY KNOX LIBRARY - RESEARCH REPORTS



5 6853 01058208 3

U15900